

Communication Architecture



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To: The Federal Communications Commission

Re: WT Docket No. 11-79, In the Matter of Spectrum Needs for the Implementation of the Positive Train Control Provisions of the Rail Safety Improvement Act of 2008

Comments

I am an independent consultant in the rail industry, meaning that I neither do sales for nor accept commissions from suppliers. My 38+ years in the industry include Director (Chief Engineer) Communications (wireless) and Director Advanced Traffic Control for Class I railroads. In the latter position I conceived and directed the development of the first overlay PTC system that provided the primary foundation for the current PTC systems being pursued by the freight railroads to meet the 12/31/2015 PTC mandate as stated in the Rail Safety Improvement Act of 2008. In addition to my ongoing involvement with PTC, I have performed market studies and held strategy sessions regarding wireless for Class I railroads, major suppliers, and the FRA. My credentials as to PTC and wireless technologies in the railroad industry are provided as an Attachment to this submission.

I have been commissioned by the Skybridge Spectrum Foundation to submit an objective analysis of the use of the 220 MHz band for PTC. As such, this submission addresses two primary points:

First, I am providing below a brief understanding of PTC as to its designs, capabilities and benefits. This is critical to do so as to ensure objectivity when addressing 220 and PTC in that there continues to be an unfortunate amount of disinformation being put forth by those with an unjustified bias to implement PTC, including suppliers and even the FRA.

Second, I am providing a brief understanding of the use of wireless technologies in the railroad industry in general, and the applicability of 220 band for PTC specifically.

PTC: WHAT IT IS ... AND WHAT IT ISN'T

To understand PTC first requires an understanding of the three categories of systems that are used by railroads, both freight and passenger, in various configurations across the globe.

1. Traffic Control systems provide for the integrity of train movements, of which there are two primary types: signaled and non-signaled. These systems are responsible for

providing the *movement authorities* (permission) to trains to advance without conflict with the movement of other trains. The primary role of traffic control systems is to avoid accidents due to errors that train dispatchers could make in routing trains manually. These systems are often referred to as being “vital” given their purpose of providing for safe operations.

2. Traffic Management systems are being increasingly used by railroads to increase the efficiency of the traffic control system in effect. That is, traffic management systems provide for the business perspective of running a railroad by advising train dispatchers how to improve the efficiency of the traffic control system that provides for the safety. These systems are advancing now in the U.S. given the substantial increase in rail traffic in the last decade, largely due to rapid growth in intermodal traffic, thereby minimizing the investment railroads would otherwise need to make in infrastructure and equipment.

3. Enforcement systems are used to prevent train crews from exceeding the time, distance, and speed parameters of the movement authorities generated by the traffic control system. Enforcement systems enhance the safety of operations, but are not vital. That is, if the enforcement system is not operational, then trains can proceed safely given the traffic control system in place. Additionally, enforcement systems do not affect the efficiency of movement authority generation, as does traffic management, and therefore provide no business benefits.

From the Federal government standpoint, PTC is synonymous with enforcement system. While there are a number of enforcement systems across the globe, PTC from a U.S. freight railroad standpoint refers to a singular type of enforcement system that is required to be interoperable across all freight, commuter, and regional transit systems that operate jointly on the nation’s infrastructure. That is, the PTC systems that are being pursued by the U.S. freight railroads differ substantially from the “PTC” system that is installed on Amtrak, which is referred to as ACSES (Advanced Civil Speed Enforcement System). For purposes in this submission, the term PTC will refer only to those systems being pursued by the freight railroads.

As mandated, PTC has 4 core objectives: 1. Keep trains from hitting trains; 2. Keep trains from overspeeding; 3. Keep trains from endangering workers in work zones; and 4. Keep trains from moving through mis-aligned switches.

As to design, PTC is a *locomotive-centric* system that operates outboard of the traffic control and traffic management systems. That is, when movement authorities are generated by a traffic control system, either in the dispatching office or from equipment along the wayside, then the parameters are automatically sent via wireless data to the on-board PTC platform. The on-board platform then uses positioning data, e.g., GPS, to determine the train’s position relative to the speed, distance, and timing of the set of authorities currently active for the train. This is a continuous calculation by the on-board platform to ensure that the braking capability of the train is sufficient for each authority. Should the on-board system determine that the train may exceed an authority in some fashion, then the train driver is given a warning to bring the train within its braking capability, e.g., by slowing the train. Should the driver fail to respond effectively within sufficient time, then the on-board PTC platform activates the train’s braking system thereby bringing the train to a stop prior to the movement authority being violated.

As noted earlier, PTC as an enforcement system only does not provide for business benefits. Where much of the confusion on this issue comes from is first purposeful misrepresentation by

some parties, but also by the inability of some to separate the functionality from the technology. That is, PTC is an application that requires a wireless data system. Advanced traffic management is an application that also requires a wireless data system, and a very simple one at that. Hence, installing PTC is one way to get the necessary wireless platform for advanced traffic management. But, PTC does not deliver those business benefits. The case in point is that NS has implemented a very simple data system, without and before PTC, and is realizing such business benefits.

There continues to be confusion across the industry and various agencies as to PTC being vital or not (This can be a critical issue for testing and accepting PTC). This confusion is exasperated by the fact that one version of the PTC systems being pursued by some freight railroads is referred to as VPTC, with the V meaning vital. The truth here is that functionality of PTC is not vital, but the on-board platform on which the application resides is designed in a vital fashion, thereby indicating a very high reliability as to the equipment not failing.

PTC & WIRELESS

As noted above, wireless data networks are used to transmit the movement authority parameters to the on-board platform. Below, I list a number of issues relative to the use of wireless for PTC in general, and the issues associated with 220 specifically relative to PTC.

- Depending upon the type of traffic control system in place, as well as the level of traffic density, the transmission of movement authority parameters (a.k.a. targets) for an individual train can be as infrequent as an hour apart and as frequent as every 5 minutes. In any event, this is not *real-time* transmission and certainly not challenging for even moderate private or commercial wireless systems.
- Without going into in-depth detail, it should be noted that most of the Class I railroads are pursuing a PTC system design that significantly exceeds the requirements of the PTC mandate as to handling what is referred to as intermediary signals (ISs). It is not clear why they are doing so, but such a design would seemingly contribute to their justification for a complex wireless data network such as that being designed by the railroads using 220. In fact, not only are the ISs not required to be incorporated, but one Class I railroad is planning to use its current wired and wireless networks to connect both the ISs and the remaining portion of the PTC wayside infrastructure referred to as *control points*. This alternative method of communication avoids a substantial investment in a 220 network that would have otherwise been required. All Class I railroads have this same capability available to them to a great extent.
- To my knowledge, there has been no data demand analyses made as to PTC requirements. Regarding this point, I recently questioned a consultant in a management position responsible for the wireless network to implement Metrolink's PTC system. He stated that there had been no data load analysis made. I have no reason to believe that any other railroad has made such an analysis, at least not one that would support the need for 220 in consideration of other wireless options that railroads have, as explained below in **RAILROADS' WIRELESS**.

- Approximately a decade ago, UP was pursuing the implementation of a Precision Train Control (PTC™), which was to be the combination of the most advanced traffic control system (referred to as moving block), traffic management, and enforcement. PTC™ failed partially due to the phenomenal complexity of the wireless data platform that could not be cost-effectively deployed at that time. Unfortunately, the confusion between PTC™ and PTC has contributed to the misunderstanding of the latter as to its capabilities and the necessary wireless data requirements.
- Neither the PTC mandate nor the associated FRA rulemaking make any statements as to the design or technologies to be deployed in implementing PTC. This includes no statement as to the wireless technologies or spectrums to be used
- The PTC on-board platform includes a mobile access router (MAR) that permits the use of multiple wireless bands.
- Just as the Class I railroads plan to do as to having multiple wireless paths available for PTC, as provided for by the MAR, so will passenger operators be able to do so without purchasing or sharing the 220 MHz network. While they will need to have access to 220 when operating on some of the Class Is, they are free to use what they have available when on their own property.
- The 220 MHz band was purchased prior to the PTC mandate. Several Class Is that did not participate in that purchase had planned to use other existing wireless services, both private and commercial

RAILROADS' WIRELESS

I have performed studies and held strategy/tactical sessions on the use of wireless in the rail industry for nearly two decades, both as rail management and as a consultant. Arguably, the most notable and applicable to this submission are the following:

1. I was commissioned by the FRA in 2007 to perform an extensive study on the demand and supply of wireless in the rail industry. This study involved a large number of interviews and work sessions with railroad personnel, both technicians and operations management, as well as suppliers.
2. I was engaged by the Skybridge Spectrum Foundation in 2011 to write a white paper "Wireless for Railroads", partially in consideration of the effects of the PTC mandate on the railroads' use of wireless.

The results of two of those activities are summarized briefly below, as well as the reports being provided as Attachments to this submission: *Wireless Study-Lindsey.pdf* and *Wireless Report.pdf*, respectively

- The railroads' primary wireless band, 160-161 MHz that is used primarily for voice, is subject to the FCC's refarming (narrowbanding) Point & Order. This mandate requires splitting of the channels by 2013, with a subsequent split as some to-be-determined time. For the industry, this means replacing an estimated 250,000 radio units. Some

railroads initially planned to replace the analog equipment with analog equipment that could handle the initial split. Fortunately, however, the decision was made to go a digital platform in the light of the second split. Unfortunately, the railroads elected a conventional radio approach instead of a trunked radio network which would have been ideal for the most congested portions of the industry's operation, i.e., major metropolitan areas. As the result of this decision, the efficiency of the 160-161 band is substantially less than it could have been. Hence, there is little doubt from my standpoint that if the railroads went to a digital trunked operation, then the data requirements of PTC could be readily handled with the 160-161 band.

- There appears to be no strategic perspective of the use of wireless by many if not all of the Class I's individually, yet alone together as an industry. That is, the plan to use and design a sophisticated 220 network has become the default wireless network for the future of the industry without any analysis, or justification, of what is actually required. Implementing 220 along with the narrowband 160-161 will result in two parallel, powerful wireless networks across the industry supporting only voice and a modicum of data applications it seems. As noted in both of the referenced reports, the railroads can achieve substantial business value with very simple wireless data systems, and without implementing PTC. The proof of this is, again, the success of NS in deploying a simple wireless system to report the position of trains, thereby permitting them to implement advanced traffic management systems.
- BNSF had purchased the Meteorcomm network with the intention of using it for its PTC system, ETMS. That spectrum is available nationwide and can readily reside on the current tower infrastructure that the railroads have for their 160-161 and 900 MHz networks.
- With 220's inferior propagation capability compared to 160-161 MHz, the railroads will be required to add additional towers to some extent to build a parallel wireless network.
- The railroads' use of the 900 band, that was originally freely granted by the FCC for an advanced train control system 2 decades ago, would clearly not be required for its current use of supporting relatively low data applications. The railroads' use of the band has already been limited by the FCC by "ribboning" the permitted territory along the railroads' trackage.

In summary as to the use of the 220, there is no need of it for PTC alone, especially in the light of the Meteorcomm 40 Mhz band and the opportunity to deploy digital trunking in the 160-161 MHz band to meet the narrowbanding mandate. Clearly, the industry can benefit from an industry-wide network, but that opportunity is not limited to using 220. While the railroads may be able to use the 220 at some future point, I have seen no evidence to date of a strategic demand study being performed by railroads, either individually or collectively, as to how the railroads can advance with 220 or any other band. Sadly, the true cost of the PTC mandate will not just be the installation of the systems across the industry, but also the tremendous lost in business benefits in that the railroads have stalled on advancing their operations so as to meet the PTC mandate.

Lastly, it needs to be stated that the railroads are very safe. As noted in the GAO's report of December 2010 on Rail Safety (GAO-11-133, also attached), the cost of implementing PTC relative to the safety benefits that will be provided over 20 years is 20/1. While I believe that the

cost of PTC can be greatly reduced as noted earlier as to ISs and control points, as well as by avoiding 220 in favor a digital trunked 160-161, the cost / benefit ratio remains an egregious expenditure for the railroads to go it alone without Federal assistance. While the Rail Safety Improvement Act of 2008 was a knee-jerk reaction by Congress to and within less than 2 months of the Metrolink – UP tragedy, it will have one phenomenal effect on the industry that would have been difficult to achieve otherwise. That is, the PTC mandate finally brought the railroads together to pursue a nationwide wireless data network. Unfortunately, I believe the railroads reacted in a knee-jerk fashion as well as to pursuing the 220 without taking on what could be done with digital trunked 160-161 and/or the use of the Meteorcomm network, cellular systems, and perhaps other possibilities such as available via advancing technologies including software defined radio.

My objective in these Comments, as a professional in these areas and a citizen, is to advance the best interests of the nation in wise use of radio spectrum for railroad wireless and safety.

In closing, the Skybridge Spectrum Foundation is willing to sponsor the use of my services to formally or informally meet with FCC to further discuss any of the points provided in this submission, including the attachments.

Sincerely

/ s /

Ronald A. Lindsey

Attachments:

- Credentials – Ron Lindsey
- Wireless Study- Lindsey.pdf (the FRA sponsored study)
- Wireless Report.pdf (the Skybridge Spectrum Foundation whitepaper)
- GAOFRAtech.pdf

Credentials – Ron Lindsey

Ron has 38 + years in the rail industry even split between rail management and consulting. As to rail management he has held the positions of Chief Engineer Communications for Conrail (when it was a Class I) and Director of Advanced Train Control for CSX. In this latter position, he was the architect for the first overlay PTC system that provide the foundation for PTC systems being pursued by the freight railroads today.

As a consultant, Ron is independent meaning that he represents no suppliers nor accepts credentials. The primary consulting activities focus on the strategic deployment of technologies, most importantly PTC and wireless. As to these two areas specifically, his credentials include the following:

- Project Leader for an USTDA sponsored study to evaluate the feasibility of PTC and efficiency systems for the Egyptian National Railways;
- Project Leader for a proposal submitted for a FTA project regarding adapting PTC for passenger operations (not yet awarded)
- Performed FRA-sponsored study regarding the use of wireless in the rail industry
- Frequent speaker at PTC and related industry conferences including
 - Chairman of the PTC Congress, 2011
 - CBTC Conference 2011, 2009
 - PTC Conference 2008, 2009, 2010,
- PTC articles published
 - Journal of Transportation
 - IEEE Vehicular Technologies
 - Railway Age (currently a Contributing Editor)
 - A book on railroad technologies to be published in 2012
- Teach a PTC course to suppliers
- Teaches a Railroad Immersion Course to Class Is and suppliers
- Publishes a quarterly journal, **Full Spectrum**, for 15 years that has been subscribed to by Class Is, FRA, and major suppliers.

Lastly, Ron has a BS in Metallurgy and an MBA

In addition, see page 13 of Attachment 3 to my Comments in FCC Docket 11-79.

An Analysis of the Opportunities for
Wireless Technologies in Passenger and Freight Rail Operations

December, 2007

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ACKNOWLEDGMENT

This document provides the findings of a study commissioned by the FRA under the terms of the Broad Agency Agreement. The study was awarded to and performed by Ronald Lindsey, and the value of the findings is directly related to the participation by the Class I freight railroads, Amtrak, suppliers, and shippers.

Questions and comments may be addressed to Ronald Lindsey
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Appendix: Definition of Terms & Phrases*	

* Given the broad range of individuals and organizations that may read this report, the Appendix provides descriptions of terms and phrases that may not be familiar to all. The terms and phrases that are included in the Appendix will be followed by a “[†]” at their first appearance in the report.

SUMMARY OF FINDINGS

This study focused on the deployment of wireless technologies to advance railroad operations. As such, there are 5 key phrases that collectively capture the essence of this study.

1 LEVELS OF OPERABILITY

Wireless technologies can provide an unprecedented level of timeliness of data as to the status of remote and mobile resources both within the boundaries of an individual railroad as well as across the industry. This micro and macro perspective, respectively, presents the challenge of operability (usability) in deploying wireless-based infrastructures that overlay, complement, or replace traditional operational-critical infrastructures, e.g., voice radio, traffic control [†], Automatic Equipment Identification (AEI) [†], Electronic Data Interchange (EDI) [†], and telephone. As such, there are six levels of operability:

Railroad Intraoperability: the ability of a railroad to use its operating resources across its own network. This presents the classic challenge of how to manage “unequipped” units. In the case of locomotives, up to 20% of the fleet being used can belong to other railroads thereby resulting in a tradeoff between reduced functionality and increased operating costs to equip foreign locomotives.

Interoperability: the challenge of the interchange of trains between railroads presents again the tradeoff between reduced functionality and increased operating costs relative to unequipped units entering the operating railroad’s network.

Industry Intraoperability: the value of having access to a railroad’s resources when on another railroad. This area has been little explored due to the both the lack of effective access to each railroad’s data by other railroads as well as the lack of an industry-based tracking system.

Train Intraoperability: a developing level of operability as to the environment within and surrounding the train. This is an arena that has recently received some attention due to some Association of American Railroads (AAR)-sponsored activities in addition to the pursuit of Electronic Control Pneumatic (ECP) brakes [†].

Cross Industry Operability: a developing level of operability as the attention on security and hazardous materials crosses boundaries between the railroads and their respective shippers / industries.

Global Intraoperability: taking cross industry operability to the global level, again with the focus on the shipment and domestic security.

To date the railroads collectively have pursued only interoperability in anticipation of deploying Positive Train Control [†] (PTC). However, PTC is currently not a high priority, and the railroads are pursuing their individual agendas for technologies and applications that can create a harsher environment in the future for achieving interoperability. A comprehensive understanding of the above six levels of operability in line with advancing functionality, as identified in this report, could provide sufficient value for the industry to take an expanded and more progressive tack in providing for all levels of operability, with or without PTC.

2 REVOLUTIONARY FUNCTIONALITY

The use of the timely resource status data that wireless can deliver, in concert with planning and executions tools to process the data, can provide a railroad's resource managers of track time (train dispatchers), yards, crews, locomotives, cars, and maintenance crews with a revolutionary set of business processes that predict conflicts in resource allocation. This predictability will permit *proactive* resource management, in lieu of the current *reactive* fashion, thereby optimizing utilization, reducing costs, and increasing customer service. Most interestingly, only a modicum of data is required of the wireless data network to pursue these major advancements, i.e., each locomotive's position and speed status every 5-15 minutes. And, with even less frequent data as to fuel level and health, a railroad can substantially advance its locomotive fueling and maintenance processes. Additionally, aligned with industry intraoperability, is the opportunity to extend each railroad's planning and monitoring horizon beyond its own borders, as to interchange operations, so as to optimize its train lineup and management of its shipments.

3 EVOLUTIONARY DEPLOYMENT

The railroads have substantial IT and communication infrastructure upon which the railroads' business processes are based, and simply providing more timely data via wireless will not necessarily improve operations. For traditional IT architecture, such incorporation will require modification or replacement of current systems which could be viewed as being cost prohibitive. However, in several keys areas, most notably crew, locomotive, and traffic management [†], complementary systems can be readily deployed to obtain substantial benefits without significant modification, if any, yet alone replacement of the current systems. And with the requirement of only locomotive position and speed every 5-15 minutes, an effective wireless platform(s) can also be deployed relatively simply along with an industry-based tracking system through the use of owned and commercial wireless data services.

4 HIERARCHICAL IT ARCHITECTURE

Given the different levels of operability, there is the need for a corresponding hierarchical IT architecture. This is an hierarchy that begins with the locomotive communications and intelligence platform as a *mobile node* that serves as an extension of both the individual railroad's IT platform as well as that of an industry-based IT platform that services the requirements across the levels of operability for all players including railroads, shippers, equipment owners, and security services.

5 ENTERPRISE TECHNOLOGIST

The pursuit of revolutionary functionality with evolutionary deployment is beyond the scope and expected skill set of a railroad's traditional technicians and IT architects that handle the design, deployment, and management of a railroad's traditional communication and IT infrastructures. And, given the various levels of operability, this lack of scope and skill set should be addressed both within the railroads individually, were not already present, and with an industry perspective. The necessary skill set includes the ability to deliver business cases that are pragmatic, 80/20, and based upon an incremental value / incremental cost analyses that requires a mixture of business, technology, and domain knowledge. Such a discipline points to the use of *Enterprise Technologists* within the railroads, both individually and collectively, to complement the skill sets of the technicians and IT architects. Such a discipline would focus on delivering value now, instead of latter, through evolutionary development that will complement the current industry efforts regarding interoperability.

OVERVIEW

Below, background information is provided that contributed to structuring the purpose and scope of this study, followed by the objective and process that were used to perform the study.

BACKGROUND

It has been a decade since the railroads collectively performed a study of the opportunity for the use of wireless technologies. As effective as that study was at that point in providing structure in defining the critical role of wireless communications (both voice and data) for railroad operations, the environment has changed substantially in four critical dimensions to the point of minimizing the applicability of the study to the railroad industry of today.

First, the types of wireless offerings, both private and commercial, have increased substantially, along with some obsolescence. Most important has been the increasing availability of commercial terrestrial wireless data and the use of wireless networks to extend the wired-IT infrastructure and management systems to remote and mobile resources in an IT-compatible fashion.

Second, each railroad has substantially advanced its individual agendas as to wireless technologies and applications. However, there are significant differences as to their individual progress and approaches to date which has resulted in a concerted effort by the railroads in the last two years to address interoperability, albeit with a PTC orientation.

Third, there have been several key regulations by Federal agencies that will have a profound effect on wireless advancement. Most important of these are the Federal Communication Commission's (FCC) VHF narrow-banding[†], a.k.a. refarming, and the FRA's March 2005 rule-making, a.k.a. PTC rule, that permits for the quantifying of risk in lieu of its subjective evaluation. Additionally, at the time of this report being written, Congress is considering the mandating of Positive Train Control (PTC).

Lastly, the industry itself has changed dramatically including the impressive advancement of intermodal operations, infrastructure shortages, an increasing attention to security, and staggering fuel costs.

OBJECTIVE

In consideration of the changes over the last decade, this study was structured and proposed to the FRA with the following objective:

Provide a strategic perspective of the use of wireless technologies in high speed passenger and freight operations that is beyond the current use of wireless across the industry.

This study was not intended to make, nor does it provide, either a financial, rate-of-return analysis or a technical evaluation of advancing wireless technologies.

PROCESS

The study was conducted via two sets of tasks. The first set consisted of interviews with business process managers in the Class I freight railroads Amtrak, and several shippers. The discussions addressed the following points:

1. The opportunities and advantages to replace voice transmissions with wireless data;
2. The opportunities and advantages to improve the exchange of information between railroads regarding interchange;
3. The identification of data which would be required to improve current processes for managing or just monitoring remote and mobile resources;
4. The identification of planning or execution tools that are not usable, or are limited as to functionality, due to the lack of resource status data;
5. The identification of advanced business processes, and their respective advantages, that could be incorporated with more timely resource status data,
6. A sense of timeliness of the data that would be required for the advanced functionality identified above.

The second set of tasks consisted of a number of workshops held with suppliers and railroads to address particular topics as to the supply and application of wireless and associated technologies. Each workshop consisted of interactions between the participants on topics ranging from on-board communication and intelligence platforms ... to ... wayside requirements ... to ... advance asset management opportunities. In addition to the workshops, individual discussions were held with selected suppliers and shippers.

This report proceeds from here with the study's findings as to advance functionality, a structuring of operability, the means of deployment, and an introduction of a new skill set to advance railroad operations via wireless.

FUNCTIONALITY

Unlike airlines with their fixed, multi-month flight schedules that are supported with locked-in equipment types (if not specific aircraft), crews, maintenance, passenger reservations, gates, etc., railroad operations are more unscheduled than not as to traffic control and with little, if any, scheduled assignments for the supporting resources. There is a variety of reasons for why a railroad does not run to schedule, and some of them are quite valid. The primary legitimate reasons are those in which the railroad's customers make the decisions as to the release of trains, e.g., ports and mines, and the railroad is required to fit them into the lineup[†] accordingly. However, the majority of disruptions are caused by conflicted traffic management due to the lack of adequate decision tools and the required timely resource status, including train position / speed and the status of yards, that affects both the initiation of trains as well as their progress throughout a railroad's network. Additionally, this lack of lineup reliability within the railroads builds upon itself when it comes to the interchange of trains between railroads and the resulting mutual disruptions for the receiving railroad.

The management of the primary resources that are required to run the trains suffer along with traffic management due to the lack of lineup reliability. Simply stated, the effective management of train crews, locomotive assignments, track time, on-track maintenance crews, and yard operations begins with a common, single bit of information. It all begins with knowing where the locomotives are and, somewhat to a lesser extent, how fast they are moving (which is not known today). Similarly, with a modicum of additional data regarding the locomotive, its maintenance and fueling can be greatly advanced over today's processes. Below, each of these areas is addressed as to their current environment and the **Opportunity** for advanced functionality with the deployment of wireless technologies.

TRAFFIC MANAGEMENT

The effectiveness of managing assets is only as good as the data that are available as to their status ... and then only as good as the tools and processes that are available to massage the data. Unfortunately, railroads continue to manage traffic with processes based upon a century-old technology aligned with decision making tools that really aren't, i.e., track circuits[†] and dispatching systems, a.k.a. Computer Assisted Dispatching (CAD)[†], respectively. The latter is only able to present, at best, to the dispatcher where the train was at some point in time via On Station (OS) reports[†], a.k.a. Centralized Train Control messages (CTC's), but not where the train is now and whether or not it is even moving, yet alone at what speed. Additionally, the dispatcher displays are simply that of a Supervisory Control and Data Acquisition (SCADA)[†] system that presents the status of the signaling infrastructure without consideration of distances between signals. As such, the dispatcher is often left to his/her own skills and experience in finding workable

solutions in complex situations in lieu of optimal ones given the wide range of variables and lack of timely data.

In non-signaled territory [†], a.k.a. dark territory, there is not even the availability of OS reports to place a train. And, non-signaled territory amounts to roughly ½ of the trackage in North America, although it handles only 20% of the traffic and 10% of the tonnage.

The railroads have now been caught up in a Catch 22 as to data and decision making tools. That is, they haven't had the availability of timely status data for their trains and therefore have not been able to deploy mathematics-based decision tools, a.k.a. meet / pass planners [†], capable of dealing with a wide range of variables. And, since most railroads don't have, nor have explored, the tools and processes that could use timely data, they haven't yet invested in the wireless and related technologies that are now available to capture and deliver timely data.

Opportunity

Breaking into the circular logic above is at hand, as is being explored by several Class I's, but there are a number of constraints that need to be overcome including delivering the functionality (addressed below in **DEPLOYMENT**), making the business case (addressed below in **BUSINESS VALUE**), and modifying the business processes and mind-set of dispatching, as follows.

With the availability of a wireless data platform capable of reporting train position and speed with a frequency required to optimize the use of meet / pass planners, a railroad can make the transition from the current *reactive* (crisis based) traffic management processes to that of *proactive* processes. That is, with *in-time* data and the proper management tools, the dispatching process would change to one that projects traffic conflicts and provide recommendations to minimize the consequences, if not avoid the situations altogether. The consequences referred to are the costs of not meeting the business goals (a.k.a., objective functions) that management could vary by type and density of traffic via a set of various meet / pass planning tools.

The meet/pass planning tools that would be used for dispatchers to handle disruptions are directly akin to the mathematics-based tools that the railroads' transportation planning resources, a.k.a. Service Design, would use to establish and modify the schedule as required. Once the railroad is so scheduled, then the dispatcher is left with the challenge of using the meet / pass planning tools to get back to schedule in the most effective way when disruptions occur. This approach shifts a majority of the challenge of effective train movements to the planning resources where it belongs. And, that means that the effective management of the other primary resources shifts as well to the planning phase, with their respective

execution managers using their tools in a proactive fashion in lieu of the current reactive (crisis) mode. Essentially, this is the airline's model of operations.

An example of a change in mind-set required to run a scheduled operation is that of perceived inefficiency. For example, traditional railroading calls for avoiding short trains so as to not "waste" crews or fuel or track time. Those clearly are inefficiencies. However, the price of avoiding those *unstructured* (unplanned) inefficiencies can be an increase in locomotives, crew deadheading, yard congestion, and dispatching conflicts to address disruptions. With a scheduled operation, *structured* inefficiencies are built into the schedule based upon past and projected requirements, e.g., short trains will occur, but they will still operate to maintain the schedule of locomotives and crews. The argument to do so is several fold. Arguably, structured inefficiencies will be more efficient than unstructured ones. Second, the reliability of service is optimized, leading to increased customer satisfaction and revenues. Simply stated, how successful would airlines be if they used the railroad's model of operation, e.g., fly the plane when it is full enough? The airlines instead build and modify their schedules with the expectation to "fill" the planes based upon past and projected requirements.

YARD MANAGEMENT

Yard management has seen a surge recently in yard planning and execution tools in the industry, but their usefulness is still constrained by the timeliness and accuracy of the train and equipment location data. There are two primary points here.

First, there is the issue of managing the movement of switching crews based upon a train-build profile that is aligned with a reliable schedule of arriving consist and humping operations.

Second, there is the lack of timely and actual receiving yard capacity and departures being provided to the main line dispatcher, thereby providing significant constraints to efficient, if not scheduled, train movements.

Opportunity

Unlike the main-line, the tracking of trains and cars in the yards is more challenging as to the number of adjacent tracks and the interweaving of car movements in a seemingly unpredictable fashion. And, given the range of yards that exist in the industry, it is likely that there are a few categories of yard types with each one suggesting a different blend of wheel counters, AEI, GPS-reporting, video scan, switch monitoring, and other TBD technologies that could meet the timeliness and accuracy requirements. For example, for some yards it may be appropriate to use locomotive-borne *geo-fencing* for switching crews to monitor their movements. This is a technique of establishing virtual boundaries on the on-

board intelligence platform that triggers an action, e.g., reporting position, when a boundary is crossed based upon GPS, passing a switch, or some other positioning approach.

With such improved visibility into the depths of a yard's working and status, managers can better monitor and direct their resources based upon the analysis of planning tools that can't be used effectively today. Similarly, with the timely status of in-bound and out-bound tracks, the train dispatcher's efficiency can also improve dramatically as to the movement of trains on the main-line by incorporating actual yard capacity into the meet / pass planners as well as the handling of the lineup respectively.

CREW MANAGEMENT

Considering a railroad's primary resources, the management of train crews is arguably the most vulnerable to an unreliable lineup. This is due to the need to deadhead train crews to meet trains in compliance with convoluted labor agreements. This process often works with a 48 hour horizon of how the trains are moving across the railroad's network, or even more difficult, approaching from other railroads for interchange. In fact, it is not unlikely that crew management is often the first to challenge the reliability of the lineup in an effort to reduce unnecessary crew expenses and manning levels. One difference that was noted between the railroads interviewed was that one road that operated substantially more scheduled than another, was able to deadhead and work crews back without rest. The more unscheduled railroad routinely deadheaded and rested crews before working thereby resulting in a significant increase in crew costs and manning levels as well as a decrease in the crew's quality of life.

Train crews are subject to hours-of-limits rules, and accurately knowing both their on and off duty time would ensure the maximum use of their availability while maintaining compliance with the rules that is subjected to FRA inspection.

Opportunity

Whether or not the railroads could achieve the type of crew scheduling that is an extraordinary achievement by the airlines (airline crews bid each month for their schedule in a phenomenally flexible fashion), may be a worthy pursuit, but clearly impossible without a scheduled operation. However, what is achievable is the use of crew management execution tools that can balance a number of critical cost factors in an optimizing fashion based upon a reliable lineup, including deadheading-then-work versus deadhead-then-rest, outlawing, maintaining pool balances, avoiding terminal runaround, etc. Such tools are available, but they were not found to be in use in the industry. This may be due to a lack of awareness of such tools, or it may be due to the lack of lineup reliability and the inability to use

the tools effectively. Additionally, with accurate train positioning information being available, local management can be provided with the information and tools to ensure that crew are on and off duty in compliance with both their assignments and the rules.

LOCOMOTIVE MANAGEMENT

Several railroads have incorporated the tracking of locomotives into their operations by means of commercial wireless services primarily for locomotive diagnostics and selective position reports. However, the frequency of that reporting is not sufficient for the proactive asset management functionality discussed above. One reason for the low frequency may be the cost of providing such reporting via commercial services and the lack of identifiable benefits as per the previously mentioned tools/data Catch 22. Additionally, foreign locomotives running over a railroad's property will most likely not be providing any tracking information to the operating railroad, and their use can amount to 20% of the fleet at any given time.

Railroads do obtain locomotive position reports from the AEI infrastructure that reports consist movements across a railroad's network, but that discrete reporting process is not sufficient for proactive traffic management. Lastly, locomotives approaching interchange are not necessarily reported to the receiving railroad in a timely fashion for their proper handling, e.g., fuel levels, whether the locomotive is equipped for distributed power[†], position in consist, etc. This last point indicates that there is both an intra-railroad and inter-railroad challenge to tracking locomotives.

Opportunity

While commercial wireless permitted the initial implementation of advance locomotive tracking beyond that of discrete AEI reads, it seems now that those same services may have become a constraint for railroads in moving forward with industry-wide locomotive and other asset management systems. But, that is only true to the extent that a business case has not been built that would present the financials for taking action on the full spectrum of applications identified above with either commercial and/or private wireless alternatives.

While making the business case would be the expected approach to moving forward, at least one Class I's CEO has simply mandated the railroad's fleet to be equipped with location reporting capability thereby breaking into the tool/data Catch 22 and providing the opportunity to begin building the management systems that can use that data as described above. And, another Class I is providing for a system-wide wireless data platform that can be so used, although it has yet to make the transition to an on-board reporting platform for its locomotives.

LOCOMOTIVE MAINTENANCE

Railroads are required to perform different levels of maintenance on locomotives on a 92 day, 1, 3, & 5 year basis. This prescriptive maintenance process is not based upon any diagnostics of the engine's health and suggests that engines may be spending valuable utilization time sitting on a shop track ... which leads to an artificially-high number of locomotives and excessive maintenance costs.

While some railroads have used wireless networks to monitor the health of their locomotives with the objective of avoiding in-service disruptions via predictive analysis, there is still the issue of foreign locomotives operating over their property, and the inability to obtain their health data. The point is that if you operate it, then you deal with the maintenance and operating consequences, regardless of ownership. Conversely, there is the issue of a railroad's locomotives running on foreign railroads and not being able to capture health data in those situations. Hence, in addition to the intra and inter-railroad requirement for tracking locomotives, there is also a need for intra-industry access to the locomotive's health.

Opportunity

With the availability of locomotive diagnostic data from across the industry, and the tools which can process that data for predictive analysis of the engine's health, the railroads could move to *performance-based* maintenance to extend if not replace current prescriptive processes with arguably increased reliability of locomotive operation while decreasing maintenance costs and increasing utilization. The capability to capture this data on an industry basis will be available in the Equipment Maintenance Information System (EMIS), an AAR sponsored system that is due for full implementation in 2009. However, at this point, railroads involved in interchange are not required to report activity associated with locomotives as they are with rail cars. By integrating this data with the existing Event Depository Data Base that captures movements in the industry, there is the opportunity to not only track the position and projected health of locomotives, but to implement planning tools for setting up the movement of individual locomotives to minimize maintenance costs while increasing utilization.

The availability of wireless data can facilitate also the handling of in-service engine troubles in service via an established communication link between train crews and maintenance help desks that can monitor, if not adjust, the engine's critical operating functions.

Lastly, as with locomotive management across the system, the monitoring of locomotive movements through the shops can lead to reduced shop time and congestion, thereby increasing locomotive utilization. Wireless is one means to provide for this tracking.

LOCOMOTIVE FUELING

Nearly 90% of the industry's locomotives are without electronic fuel gauges that could provide fuel levels if wireless data were available to report such dynamic information. In that the data are not available, several railroads have very conservative practices of fueling locomotives to avoid running out of fuel on the main line. Hence, a substantial amount of fuel and locomotive utilization is spent by locomotives sitting on fuel tracks awaiting fuel that in reality may not be required at that point.

In addition to their own fueling facilities, railroads also contract fuel delivery when deemed necessary. These direct-to-locomotive (DTL) services charge a premium price, and the opportunities for unnecessary fueling, if not fraud, are significant.

All of the above contributes to the difficulty in determining the fuel burn rate for individual locomotives. This information is important for evaluating both locomotive and engineer performance, determining the distance that the engine can be operated, and obtaining a fair evaluation of fuel levels at interchange when locomotives cross railroad borders.

Opportunity

The use of electronic fuel meters, both on-board locomotives and fuel trucks, with the transmission of the fueling activity by locomotive in a timely fashion to the various planning and management systems, can likely deliver significant savings in fuel costs via proactive versus reactive fueling practices, while providing for fair interchange accounting, increased locomotive utilization, and increased traffic velocity. These data will also provide for determining the accurate burn rate of locomotives that further tightens the fueling process while providing guidance to train crews for efficient operation. Lastly, there is the opportunity for the railroads to minimize the cost of fuel relative to varying state & province taxes by so planning fueling activities based upon accurate fuel tank status data.

POSITIVE TRAIN CONTROL

The greatest source of train accidents is that of train crew errors with the violation of the speed, time, and/or distance parameters of the movement authorities[†]. To prevent these errors, PTC systems are partially deployed or under development across the industry with 3 core objectives as defined by the RSAC-PTC[†] effort several years ago. That is, a PTC system is expected to

1. prevent train-to-train collisions,
2. prevent over-speeding, and
3. prevent trains from endangering on-track workers.

Given the high safety level of railroad operations in general, the incremental safety benefits of implementing PTC on its own are not sufficient to cover the capital investment[†] for the infrastructure required, and therefore PTC has not been mandated by the FRA. However, at the time of this report being written, Congress is considering the mandating of PTC across the industry.

Opportunity

The FRA's PTC rulemaking, provides the opportunity for a railroad to implement PTC as a safety balance against changes in operations that may be perceived to, or in fact do, increase risk, and that have sufficient business benefits to more than cover the expenditure for PTC. The most notable operational changes include one-person crews, the reduction or avoidance of signaled territory operation (discussed below), and operating switches from the locomotive in dark territory (discussed below). Hence, PTC can be a facilitator in obtaining business benefits via other applications that may not otherwise be obtainable due to their individual increase in risk, whether real or perceived.

TRAFFIC CONTROL

As mentioned earlier, the majority of a railroad's traffic runs over signaled territory based upon the century-old technology of track circuits[†]. This results in a fixed block handling of trains, as with traffic lights in a city, that automatically provides the aspects (the equivalent of red, yellow, and green highway traffic signals) for trains to advance. That infrastructure provides the vitality[†] of operations and, as such, requires substantial maintenance to maintain and ensure its reliability.

In non-signaled territory, the vitality is provided via a rather simplistic software program, referred to as a *conflict checker*, that maintains the status of track occupancy and generates movement authorities if no conflicts occur when the dispatcher makes a movement authority request. The original form of this process is the *train sheet*, which is literally that - a piece of paper, that provides the same process for movement integrity. Once generated, the movement authority is read by the dispatcher to the train crew over the voice radio, followed by a read-back by the crew. Any misunderstanding results in a repeat of the process. In addition to the effect of not having accurate knowledge of train position and speed, it is this voice transmission process that greatly limits the level of traffic that can be handled by the dispatcher in dark territory.

Opportunity

Both signaled and dark territory provide for the safe operation of railroads by preventing train dispatchers errors in directing the flow of traffic. Therefore, signaling is used to provide greater traffic throughput due to the lack of any positioning information as well as the inefficiency of voice transmission of

movement authorities in dark territory. But, the signaling operation has a high cost as to initial capital investment and on-going maintenance. Hence, the use of wireless data to transmit the movement authority efficiently, a.k.a., digital authorities, as well as reporting train position and speed, could result in the reduction or avoidance of signaled territory, all other factors being made equal. In this case, those factors are the consideration for broken rail detection, that is inherent in track circuit technology, and the perceived, if not real, perspective that signaled territory is safer than dark territory. These two issues can be readily addressed by low-grade track circuits sufficient for broken rail detection and the deployment of PTC, respectively.

In addition to the transition or avoidance of signaled territory in favor of dark territory, is the deployment of Communication Based Signaling (CBS) which eliminates the need for wayside signaling infrastructure. CBS is currently being promoted by a number of suppliers in the industry to use wireless technologies to transmit aspects directly to the locomotive from a central “vital office” for display in the locomotive cab, a.k.a. cab signaling. The vital components that generate the aspects currently along the wayside would be moved to the central office and train location would be provided by a TBD technology in lieu of track circuits, thereby providing a virtual fixed block operation. With CBS, there still would be the issue of providing broken rail protection, as with the transition from signaled to dark territory, but the incorporation of PTC would be relatively straight forward in that most of the authority parameters (aspects) would already be on board.

Lastly, there is the ultimate in traffic control referred to as *moving block*. This is a real time, process control version of CBS that continuously generates authorities so as to provide a safety zone around a train, in lieu of fixed blocks, based upon the train’s braking capability. However, the data requirements of moving block where it would be most needed exceed the capabilities of existing, cost-effective wireless technologies. However, in between moving block and CBS is the opportunity for *flexible block*, which is the discrete generation of moving authorities that would vary in length based upon traffic density. Both moving block and flexible block would require the development of a software-based vital office that would be a substantial effort beyond the CBS approach that centralizes the current, well-proven wayside components. Neither moving nor flexible block are known to be under development within the North American market.

MOBILE NODE

The railroads have been focusing primarily on the locomotive’s on-board intelligence and communication platform for safety purposes. That effort has not been expanded significantly yet to incorporate the business and operating perspectives of the locomotive. As reflected above with the individual discussions regarding locomotive management,

maintenance, and fueling, several railroads have little, if any, coordinated activities between the respective departments within their railroad, yet alone across the industry. The unfortunate, but unnecessary, consequence of this separation is the lack of the integration in building the business case to bring the various locomotive-borne applications together for a common communication, positioning, and intelligence platform. While the issue is complex, the benefits are very promising once pursued. However, as addressed below in **DEPLOYMENT**, wireless-based applications are challenged by transmission constraints as to throughput, reliability, and coverage.

Opportunity

For other than locomotive-centric applications, the locomotive should be provided with an intelligence platform that minimizes the need to transmit information to and from the wayside and office systems. As such, this on-board platform serves as a *mobile node* on the railroad's IT platform that provides the basis to pursue a number of opportunities for advanced functionality in an integrated fashion. The possibilities include the obvious, e.g., PTC, work order, flexible block, digital authorities, EOT, customer-gate interaction, engineer performance, and interactions with on-track work gangs. However, what has yet to be considered with the availability of a mobile node is the integration of an intra-train communication platform, as identified in the original demand study, but for which there were no pragmatic technologies at that time. This capability would add on a variety of sensor and monitoring applications including shipment health & integrity, equipment health (e.g., bearings, etc.), track geometry measurements, distributed in-train force monitoring, selected braking criteria based upon consist, and other yet-to-be-imagined capabilities.

REMOTE SWITCH CONTROL

In signaled territory, train dispatchers direct trains by the alignment of switches in the rail. The dispatcher effects these alignments by making requests of the vital wayside infrastructure, the same infrastructure that provides the aspects in the signaling equipment. In dark territory, that infrastructure does not exist and the train crews are required to manually operate the switches. This activity can require a great deal of time, as well increased risk to crew members, as they off-board the train, operate the switch, and then walk the train distance to get back on board.

Opportunity

With wireless telemetry, the train crew can operate an equipped switch from the locomotive cab. Similar in concept to the dispatcher's activity in signaled territory,

such an activity would be done in a fashion so as to not violate another train's authority. This capability is directly compatible with PTC deployed in dark territory that is currently monitoring the switch position to determine which track the train is on as well as to provide for enforcement should the crew attempt to violate their authority as to movement and speed through the switch.

MAIN LINE WORK ORDER

A number of railroads have developed wireless-based work order systems for their dedicated industrial switching train crews that are used to deliver cars to/from the shippers and the railroad's yards. However, on the main line there is a significant amount of activity that takes place with what would otherwise be through-trains to service shippers beyond the limits of industrial switchers. This activity can play havoc with the railroad's operation both as to disruptions to traffic management as well as extensive delays to the affected train as the crew manages the process with imperfect information as to car locations, trackage, etc. Finally, there is the possible effect that the rearranged consist may have on switching and train building activities at the destination yard.

Opportunity

In addition to the type of information that is made available to yard and industrial switching crews, main line train crews could be presented with a schematic of car locations along with switching order, with the final consist transmitted to the appropriate system(s) prior to the train arriving into a yard.

WAYSIDE MAINTENANCE

The wayside signaling and grade crossing infrastructure that provides for the integrity of railroad operations and the public's safety, respectively, is subjected to rigorous, continuous testing processes, regardless of the actual condition of the equipment. This process requires on-site presence. For coordinated combinations of tracks and switches, a.k.a. interlockings, multiple individuals are required for observation only in addition to the maintenance and testing effort.

Opportunity

As with the discussion above regarding locomotive maintenance, the availability of timely health and diagnostic data as to wayside infrastructure can provide the basis for performance-based maintenance that extends, if not replaces, the prescriptive process. Additionally, on-site maintenance personnel can be provided with endless access to diagnostic material including history, diagrams, and real time connection with help desks that can monitor, if not affect changes remotely. As to complex interlockings, wireless can be used to provide visual observation and data acquisition of associated locations in lieu of manual observation.

ON-TRACK MAINTENANCE

To train dispatchers, the work zones for on-track work forces are trains that don't move thereby consuming valuable track time, and over which they have little to no control. From the workers' perspective, they are subject to the threat of train movements approaching their work zone about which they are not kept current, if even informed. While most work zones are protected by an authority process that requires a communication between the train crews and the work gang's Employee-In-Charge (EIC), there are many mobile workers with and without fixed work zone limits that are deployed with only a "watchman lookout" who is watching for approaching trains. According to one major railroad, these lookouts are costing them "millions" for otherwise unproductive labor. Lastly, there is also the opposite perspective of on-track workers leaving their protected zone and placing themselves in danger with legitimate train movements.

Opportunity

The opportunities for wireless are several. First, by providing on-track workers with some combination of train movement monitoring and proximity warning system, the lookout positions can be eliminated by maintaining a virtual protective barrier around the work areas, whether changing or static. Second, whether or not Positive Train Control (PTC) systems are installed that currently do not directly integrate the EIC authority process, a digital authority process would be a significant improvement in safety as well as productivity by eliminating the current voice communication process between train crews and the EIC. Lastly, one railroad has deployed a High Rail Compliance System that results in an alert to the train dispatcher when an on-track maintenance vehicle has violated the boundaries of its authority.

INTERMODAL OPERATIONS

Although not included in the original scope of the study, the intermodal industry is addressed below relative to the rail interface. It presents a phenomenal challenge to the tracking of both assets and shipments with the rail component being arguably the most reliable. There are three primary issues: 1. asset utilization, 2. shipment tracking, and 3. shipment integrity & health.

1. Asset Utilization

The challenge of asset utilization begins with the lack of available tracking data. For intermodal movements, this issue is directly due to the presence of the **beneficial owner**, i.e., the party who is in possession of the equipment / shipment at any given time, but is not the true owner. The true owner of the equipment, if not also the shipper, has little interest in tracking the equipment other than by knowing the "chain of custody", and the shipment tracking processes provide for that level of granularity. However, within any given beneficial owner operation, the tracking data doesn't normally exist because no one beneficial owner is willing to make the capital investment to provide for such reporting given the short period of possession.

2. Shipment Tracking

As difficult as it is to track the equipment, it is even more so relative to containers within yards and along the main-line. With varying granularity of shipment tracking in concert with the reported unwillingness of railroads to share consist data with other railroads, the shippers are left without cross-industry visibility of the advancement of their shipments.

3. Shipment Integrity & Health

Smart seals for containers have been developed and selectively deployed to provide indication of when tampering has occurred. But, without a pragmatic communication link to get this data to the appropriate parties, a great deal of security is lost. And, as to the consideration of health, there is no ability to provide exception notification for the majority of rail traveling time.

Opportunity

As to the tracking of shipments, it appears that a depository is required for the industry that is independent of the individual railroads. This is a depository that would capture all movements relative to trains and consists, and permit subscribers to have access to the appropriate data. This concept is addressed below in **IT Architecture**.

The remaining two areas of utilization and integrity/health have the opportunity of being integrated. This is an integration that involves ownership, technologies, and operations. It is possible that chassis could be considered as a mobile node for intermodal just as the locomotive can be for the railroads. Consider the following.

Several years ago, the Federal government paid for the development of a chassis mounted unit that would report position on some scheduled basis, e.g., 3 times a day, recognizing that RF transmission power would be a major challenge in the pragmatic deployment of these devices. Subsequently, there was some degree of effort to tying in the reporting of electronic seals with chassis-mounted unit. By linking these devices with chassis-mounted reporting units, that were originally designed for chassis management, the basic platform is there for exception monitoring of shipment integrity, or health if those detection devices are so incorporated within the unit. To date, the communication link for the chassis-mounted unit has been cellular-based, given the point that the handling of containers when on trucks would need to rely on services provided along the highways. But, what about when those containers are on the rails? This is same multi-mode communication issue that confronts the railroads with their individual wireless agendas.

The problem remains as to who will make the investment in any positioning technology. There is one major type of exception to this consideration, and that is when equipment enters and leaves a beneficial owner's confined (controllable) area, e.g., an intermodal yard. The use of temporary tracking devices that can be easily applied and removed can handle that level of tracking, for which there is tremendous value. However, as to the remainder of the supply chain, there needs to be some unifying force or entity. One answer may be the use of major chassis pools and agreements within the industry, if not a Service Bureau that takes on the capital investment and management of the data. Another possibility may be the consideration of domestic security and the availability of Federal funds. Again, this issue is one more Catch 22 as to systems and data availability, but with the beneficial owner twist.

Intermodal introduces two other levels of operability, i.e., Cross Industry and Global Intraoperability, relative to shipment tracking, integrity, and health.

THREAT MANAGEMENT

After 9/11, the railroads went through an extensive risk analysis of their infrastructure and operations relative to terrorist-based threats so as to "*harden the targets*". That analysis would have been bounded by the capabilities of the technologies at that time to monitor and control remote and mobile resources.

With the lack of information available for this study regarding the objectives and results of the railroads' effort, it is possible that there is significant value in expanding the scope to consider threats other than those of terrorists. The reason for this is one of financial evaluation and willingness to make investment in technology. That is, given that the railroads were without any significant opportunities for deploying wireless data at the time of the 9/11 analysis, there had to have been constraints on what would be considered in the identification of the *critical infrastructure*⁺ and how to monitor and protect it.

In addition to the shipment integrity discussed above relative to intermodal, there is also the issue of interagency communications, whether voice or data, that is not there today, most likely.

Opportunity

Would the railroads' post 9/11 analysis be different today if they would take a wireless data approach now? With the currently-realistic constraints of limited, cost-effective, wireless data removed, it is very likely that the type of systems, processes, and equipment deployed for terrorist and other-than-terrorist threats could be significantly expanded, the lack of an acceptable, risk-based ROI notwithstanding. For example, the monitoring of the integrity of remote facilities, e.g., alignment on bridges and expanded video, are well in reach at this point. As

to critical rolling stock, one major chemical supplier has equipped its fleet of 700 Toxic Inhalation Hazard (TIH)¹ tank cars to locate and monitor their integrity on an as-needed basis. This information is coordinated within their industry, and the railroads subsequently are made aware of possible problems as deemed appropriate.

Lastly, the opportunities for wireless would likely include both voice and data requirements for inter-agency interaction of railroad, municipal, state, and Federal resources.

PASSENGER SERVICES

While Amtrak has many of the same primary operation challenges as freight railroads, there are several key differences as to its requirements for wireless technologies and how those requirements can be met.

As to additional requirements, its customers are on-board, or at stations, and its perspective of customer service as to maintaining schedule and providing associated services is immediate. That includes providing communication and internet access to its customers, status-of-train signage at stations, and handling on-board purchases, including services and tickets. This capability includes being able to take advantage of the changing availability of various services on board, e.g., berths, etc., given the dynamics of the passenger manifest. Also, from a security standpoint, Amtrak is looking to track the passenger manifest and to provide the communication requirements for a mobile police force.

As to meeting its requirements, Amtrak is at a major disadvantage given that 95% of its operations are over another railroad's property and therefore without private wireless coverage, voice or data. Its view of intraoperability encompasses the industry, and it relies on information from the railroads as to the location of their trains and on commercial cellular services to service its basic crew and police communications other than traffic control.

Opportunity

Amtrak is reportedly looking at private wireless networking over the Northeast corridor that it controls for providing a number of the customer services described above. However, for the majority of its operating territory, it has little choice at this time but to rely on commercial services to meet the expanded functionality that it envisions for its passengers and security purposes given the inconsistency of private wireless data infrastructure across the Class I railroads. Amtrak would be able to benefit substantially from an industry tracking system as discussed below in **SCENARIO**.

OPERABILITY

The use of wireless technologies within railroads to advance operations carries with it the challenge of *operability*, i.e., the ability to use wireless technologies not only within an individual railroad's boundaries but also across the industry for the advantage of all roads when operating foreign equipment over their respective networks.

In the latter part of 2005, the railroads agreed to take on operability as it relates to the interchange of trains between railroads, a.k.a. *interoperability*, with a series of task referred to as the *Roadmap to Interoperability*. The underlying motivation was that of pursuing one-person crews and therefore the objective of seamlessly implementing Positive Train Control (PTC) across the industry - noting the previously discussed point of PTC providing a safety balance for the possible increase in risk of one-person crews. However, with a stay in the negotiations between railroad management and labor to pursue one-person crews in November, 2006, the priority of interoperability to facilitate industry-wide PTC has given way to each railroad's individual agenda of technologies and applications. Unfortunately, these singular railroad efforts can result in increasing the complexity of, if not the resistance to, obtaining interoperability for several reasons including evolving infrastructure as well as additional technical interfaces and business processes which will need to be incorporated at some point in the future.

The challenge of operability is significantly greater than just that of interoperability. In the deployment of wireless-based applications, there are six levels of operability to be considered as identified in **FUNCTIONALITY**, i.e., *Railroad Intraoperability*, *Interoperability*, *Industry Intraoperability*, *Train Intraoperability*, *Cross Industry Operability*, and *Global Intraoperability*.

Railroad Intraoperability is a common challenge for a railroad when it implements a new function or deploys a new technology system wide. Until the entire affected infrastructure and/or fleet is configured properly, the application will be required to deal with the "unequipped" units in some fashion. As such, the railroad will be making a tradeoff during implementation that pits the capital investment for complete or rapid installation against the compromise in functionality and/or the operational cost of managing around the unequipped units, e.g., swapping in / out devices on the lead locomotive of trains to provide for the required functionality in lieu of equipping all locomotives.

As to the locomotives specifically, there is an additional complexity for a railroad's intraoperability as to the use of foreign locomotives which can be up to 20% of the fleet at any given time. Additionally, when dealing with a railroad's

use of VHF, its primary wireless voice network, the issue may involve 10's of thousands of radio units as well as the lack of available frequencies that can be assigned permanently or used as a buffer during transition given radio channel allocation across the industry.

Interoperability, again, refers to the challenges of the interchange of equipment across railroad boundaries. As such, the tradeoff is still the same as that of railroad intraoperability in the consideration of capital investment, functional benefits, and operating costs, but its handling is raised to an industry level. This means that the AAR is involved to ensure industry-wide participation by establishing some mixture of interchange rules, specifications, and guidelines that the railroads have agreed to collectively.

Industry Intraoperability involves having access to the status of resources regardless of over which railroad they are operating. Whereas railroad interoperability and interoperability issues for each railroad involve owned and foreign assets on its property, industry intraoperability involves a railroad's assets on other railroads. This level of operability has been rarely discussed or pursued, and it presents a significant opportunity to railroads for improved operations as noted in **FUNCTIONALITY**, including traffic management, the locomotive application suite of management / maintenance / fueling, and threat management.

Train Intraoperability focuses on the mobile node perspective discussed in **FUNCTIONALITY**. With the developing expansion in scope of the locomotive's communication and intelligence platform to include intra-train and track monitoring, the challenge shifts to dealing with 1.3 million units of rolling stock in addition to only the 22,000 locomotives involved in interoperability.

Cross Industry Operability is a developing level of operability as the attention on security and hazardous materials crosses boundaries between the railroads and the respective shippers / industries. For those shippers that have attached sensors to their owned rolling stock, e.g., tank cars for hazardous material, they will know before the railroad that the hatch has been opened, or the shipment has been tampered with, and will notify first their industry association and finally the railroads.

Global Interoperability is taking cross industry operability to the global level, again with focus on the shipment and domestic security.

Not all of the applications described in **FUNCTIONALITY** need to consider all levels of operability, as shown in the following table.

		OPERABILITY LEVEL					
		Railroad Intra	Inter	Industry Intra	Train Intra	Cross Industry	Global Intra
FUNCTIONALITY	Traffic Management	√	√	√			
	Yard Management	√		√			
	Crew Management	√		√			
	Locomotive Management	√	√	√			
	Locomotive Maintenance	√		√			
	Locomotive Fueling	√	√	√			
	Positive Train Control	√	√				
	Traffic Control	√	√				
	Mobile Node	√	√	√	√		
	Remote Switch	√	√				
	Main Line Work Order	√	√				
	Wayside Maintenance	√					
	On Track Maintenance	√					
	Intermodal Operations	√		√	√	√	√
	Threat Management	√	√	√	√	√	√
	Passenger Services	√		√	√		

What is most significant about this table is that the value of operability far exceeds the singular pursuit of one-person crews and thereby introduces the consideration of how the railroads may want to move forward in addition to the current programs stemming from the Roadmap to Interoperability. Arguably, the best way to begin is to identify the business value associated with each of the areas listed.

BUSINESS VALUE

It is not the intent of this study to provide a financial analysis that would be sufficient to make an investment decision regarding the deployment of wireless and related technologies. However, it is the intent to expose the areas of value by functionality so as to heighten the awareness of the opportunities that may indeed lead to appropriate financial analyses (business cases), both within the individual railroads as well as from an industry perspective given the various levels of operability. One of the driving factors for doing such analyses is the consideration of the FCC's Report & Order that deals with narrow-banding (discussed in **WIRELESS ENVIRONMENT**). This action will eventually result in the necessity to replace the current, mostly-analog VHF infrastructure with a digital one. This means that the objective of the business case has changed from that of justifying an investment to that of optimizing the return on a required investment, assuming the railroads wish to retain usage of this most valuable spectrum. However, even without the narrow-banding requirement, it is believed that the value of the opportunities identified in this study would be shown to be more than necessary to make the transition to a digital VHF platform sooner instead of latter based upon the following cursory evaluation.

While each railroad will have its individual slate of benefits that it uses to consider the investment in technologies, the following 6 categories are being considered in this study:

Traffic Velocity: minimizing travel time over the main line, which in turn has an effect on resource utilization, direct costs, and customer service;

Resource Utilization: minimizing the unproductive use of resources, including crews, track time, locomotives, maintenance crews, and yard dwell;

Direct Costs: minimizing the costs associated with operating the railroad, including maintenance, fuel, and crews;

Infrastructure: minimizing the requirement for infrastructure including wayside and on-board;

Customer Service: maximizing the level of customer service in pursuit of increased revenue; and

Security & Safety: maximizing the cost-effective level of resource and shipment security, as well as the safety of operations.

DEPLOYMENT

In the abandoned moving block attempt mentioned above, a primary application killer was the inability to deploy a cost-effective wireless solution that could provide the required data throughput. Usually, however, in the railroad industry it is a second dimension of wireless that is the most difficult to overcome, i.e., the challenge of coverage. The railroad's unique footprint of 10,000's miles of ribbon operations with intermittent hubs, has proven to be cost prohibitive for a number of projects that could not singularly justify the investment. Hence, commercial services have often been, and continue to be, utilized to provide the necessary coverage for individual, wireless-based solutions.

Coverage and throughput are not the only challenges to the deployment of wireless systems; there are three other areas. First, there is the challenge of dealing with the wireless environment, the parameters of which include installed infrastructure, regulatory issues, commercial versus private network opportunities, and advancing technologies. Second, there is the issue that even if the data can be delivered, it is likely that the current management systems are not able to use the data in a most-effective fashion. This is due to the fact that the to-be legacy systems are likely structured based upon a very limited level of data timeliness and accuracy than that available via wireless, e.g., moving block requiring a vital office development. Third, with the addition of the mobile node, a modified IT architecture is required that can effectively manage the positioning dynamics of resources, dynamics that are not to be found in the point-to-point communications of a wired, fixed node distributed or centralized IT platform.

Together, the five factors of coverage, throughput, wireless environment, management systems, and IT architecture suggest that the railroads may benefit from an approach to the development and deployment of wireless-based applications and the related infrastructure that complements the current efforts associated with the Roadmap to Interoperability. The railroads may benefit from an *evolutionary* approach to deploying the wireless-based applications identified in **FUNCTIONALITY** that can be delivered relatively quickly and effectively while they continue with an industry effort that is clearly a number of years away from actual implementation given technical, financial, and political considerations. A **SCENARIO** for such deployment will be addressed below following a discussion on the wireless parameters of coverage & throughput, the wireless environment, issues of management systems, and IT architecture.

Coverage & Throughput

Incorporated into the initial wireless study a decade ago was a structuring of wireless's coverage and throughput dimensions as associated with the applications identified then. To a great extent, that understanding remains applicable today, albeit with greater flexibility given the explosive advancement of wireless technologies.

COVERAGE: Unquestionably, a major issue for implementing wireless systems across freight railroads is that of terrestrial expanse. However, not all applications are required everywhere. There are clusters of applications that can be related to four different types of coverage, as follows.

Main-line: the inter-city traffic that includes most of a railroad's terrestrial expanse;

Metropolitan: the major metropolitan areas that include multiple railroad facilities;

Yard: an individual terminal/facility; and

Group: a number of users that require communications between themselves when they are together and then are disbursed, e.g., work gangs, trains, disaster teams, etc.

THROUGHPUT: Throughput is not just an issue of baud rate as one would think of relative to wired communications. When exposed to the wireless world, one quickly learns that this untethered environment is challenged with a number of message integrity issues including dead spots (no signal), EMF interference, restricted bandwidth, user contention, limited signal propagation, and the occasional dead battery for the hand-held radios. Given this set of challenges, it is appropriate to define the throughput attribute in terms of the different types of transmissions of which there are six.

Monitor: the transmission of remote data to a source of intelligence. The data flow is inbound only and consists of small data bursts that occur infrequently on either a routine or as-required basis;

Voice: a two-way transmission that occurs randomly and may be of relatively long duration;

Transaction: the interactive flow of data that is short in nature, but may occur quite frequently;

Data Transfer: the two-way flow of considerable volumes of data that will occur with some predictability as to location or time of day;

Loose Control: often referred to as SCADA in other industries, this two-way flow of data is associated with the remote control of equipment that is perhaps timely, but not safety critical as to the timeliness of the data, e.g., code lines[†];

Tight Control: the two-way flow of control data that is operationally and safety critical and, therefore, the throughput attributes must maintain tight variances, e.g., moving block.

With 4 areas of coverage and 6 types of throughput, the wireless requirements of a railroad can be structured into 24 combinations as shown in the following matrix.

		COVERAGE			
THROUGHPUT		MAIN LINE	METROPOLITAN	YARD	GROUP
	MONITOR	1	2	3	4
	VOICE	5	6	7	8
	TRANSACTION	9	10	11	12
	DATA TRANSFER	13	14	15	16
	LOOSE CONTROL	17	18	19	20
	TIGHT CONTROL	21	22	23	24

When the applications addressed in the original study were viewed as to which blocks they fell into, there was a natural merging of the individuals blocks which led to a more practical strategic perspective. Specifically, as shown in the modified matrix below, six “wireless corridors” were identified with each being a combination of applications with similar wireless requirements. This perspective offers a pragmatic approach to tailor wireless infrastructures for shared usage by applications.

		COVERAGE			
		MAIN LINE	METROPOLITAN	YARD	GROUP
THROUGHPUT	MONITOR	MONITOR			
	VOICE	MOBILE NETWORK		YARD NETWORK	INTRA-GANG or INTRA-TRAIN
	TRANSACTION				
	DATA TRANSFER				
	LOOSE CONTROL	SCADA			
	TIGHT CONTROL	PROCESS CONTROL			

Applying this same structure of wireless corridors to the opportunities identified in **FUNCTIONALITY**, as shown in the following table, provides the beginning for building a deployment strategy for moving forward in an evolutionary fashion.

WIRELESS CORRIDORS

FUNCTIONALITY		Monitor	Mobile Network	Yard Network	SCADA	Intra-train Intra-gang	Process Control
	Traffic Management	✓	✓				
	Yard Management			✓			✓
	Crew Management	✓	✓				
	Locomotive Management	✓	✓	✓			
	Locomotive Maintenance	✓	✓	✓	✓		
	Locomotive Fueling	✓		✓			
	Positive Train Control		✓				
	Traffic Control		✓		✓		✓
	Mobile Node		✓	✓		✓	
	Remote Switch Control		✓		✓		
	Main Line Work Order		✓				
	Wayside Maintenance		✓		✓	✓	
	On-Track Maintenance		✓		✓	✓	
	Intermodal Operations	✓		✓	✓		
	Threat Management	✓			✓		
	Passenger Services		✓				

What is most notable about this table are the two highlighted columns. Between, the *Monitor* and *Mobile Network* corridors, all but one of the advanced functions can be serviced to some extent. However, the most interesting point is that the *Monitor* and the *Mobile Network* corridors represent the difference between evolutionary and revolutionary deployment, respectively. That is, they represent the difference in being able to deliver value immediately in a pragmatic fashion via a simplistic Monitor platform, while the industry continues to wrestle with the complexity of the long term perspective of a revolutionary Mobile Platform via the various AAR technical committees. As if the intrinsic challenges of developing a mobile platform were not substantially difficult on their own, the railroads are also being confronted with a FCC Report and Order to restructure their VHF infrastructure (discussed in **Wireless Environment**), that presents them with investment alternatives that have yet to be addressed with a business case analysis by individual railroads, yet alone at the industry level.

The Monitor corridor is a no-brainer, a throw away solution that will pay for itself immediately. It is an individual railroad approach that doesn't require standards, a data model to size, or even a complex business case to be made. In fact, it is an approach that one railroad CEO has taken to break into the aforementioned Catch 22 , i.e., having the

data ... so as to use the tools ... so as to get the value to pay for the data. This is a simple “Just Do It”, and for an individual railroad it makes a great deal of sense to get rolling on advanced functionality. But, from a multi-operability standpoint, there are some other challenges to be considered. Fortunately, those challenges are actually quite straightforward and readily achievable, as will be addressed in **SCENARIO** below.

Wireless Environment

The railroads have extensive private wireless infrastructures across their individual systems. The primary set of frequencies that have been in use since the middle of the last century for voice communications is in the 160 MHz portion of the VHF band. There are an estimated 250,000 units across the industry that operate on those frequencies. The railroads also use frequencies in the 450 & 900 MHz UHF bands for a limited amount of data for isolated applications, most notably EOT and wireless codeline, respectively. And, recently the railroads purchased 5 channel pairs in the 220 MHz range for Remote Control Locomotive (RCL)[†] and other possible uses. Lastly, one railroad has purchased a company with licensed frequency at 44 MHz and is using that network for at least its PTC data requirements. Such an inventory provides the basis for moving forward.

Since the original wireless demand study a decade ago, there have been substantial changes in the availability of wireless technologies, both for private and commercial networks. Additionally, for sometime following the study, wireless and IT were seen as separate disciplines with neither exhibiting understanding or experience in the technical challenges of the other. That has now changed with the recognition that the wireless technologies offer the opportunity to extend the IT infrastructure beyond the end of the wire so as to more tightly incorporate the mobile and remote resources into the management systems. However, unlike wired infrastructures, wireless technologies vary substantially in their ability to service the throughput, coverage, and reliability requirements of applications. And, since there is no one technology that provides the most cost effective infrastructure across the broad range of applications, it is necessary to consider a range of wireless technologies and services, both private and commercial.

Arguably, the most popular choice for wireless data for the last several years has been the usage of commercial services. As noted earlier, commercial services have been used to implement singular solutions to meet individual railroad department requirements that could not justify the installation of a private network. The good news is that railroads have been able to advance selected applications, albeit at a relatively high cost for the amount of data required when compared to a private network if it was available. However, other key applications have not been able to be advanced due to such costs. For example, as noted earlier, this same cost consideration has been a likely deterrent to moving towards a proactive traffic management functionality, given the value/data Catch 22. Therefore, a collective understanding of the opportunities for wireless is an

underlying consideration of promoting private wireless infrastructure. But, there are several other considerations as well.

As noted earlier, the railroad's primary wireless infrastructure, VHF, is subject to the FCC's narrow-banding Report and Order. This order currently requires the railroads to split each of its 25 KHz channels in the 160 MHz portion of the VHF band in half to create twice the number of channels by the end of 2013. While on the surface this seems to be an excellent idea, the challenges are substantial including providing a channel plan that allocates frequencies efficiently and fairly along with providing a multi-year, interoperable migration plan. However, due to the way that the railroads have cleverly coordinated their channels in the past at the 25 KHz spacing, they will gain very little additional channel availability, and therefore usefulness, with the 12.5 KHz spacing. Hence, without having developed a strategic perspective and associated business case of what a digital platform could provide, the railroads have invested in analog 12.5 KHz equipment to replace the 25KHz analog equipment to meet the time line of the FCC's order.

Recently, however, the FCC announced that they will be demanding an additional split in same spectrum resulting overall in a 4 for 1 split of channels to a spacing of 6.25 KHz. While this does indeed offer additional capabilities to the railroads, e.g., supporting many of the opportunities noted in **FUNCTIONALITY**, it also means that the analog infrastructure, including the recent 12.5 KHz equipment will need to be replaced with a digital infrastructure. This is estimated to be at least a \$500 million investment for the industry that would have to be spent by a TBD date for the transition. This point introduces a second consideration of advancing wireless in addition to understanding the opportunities. That is, if the order is made regarding the second split, then the railroads will have to make the investment to keep the most-valuable frequencies. This changes the business case from a return-on-investment analysis to one of maximizing the return on a required investment. And, as suggested by this study's findings, that means the sooner the transition is made, then the greater the return. This is directly opposite to the current perspective of delaying the investment for replacement purposes only.

There is one other consideration, however. In light of the in-toto replacement of the VHF infrastructure to meet the possible 6.25 KHz spacing, an infrastructure ripe for data, there is the opportunity to do what the railroads did with their wired communication backbone requirements along of right-of-way when fiber optics came into play several decades ago. That is, the opportunity is there to bring in a 3rd party to make the investment in whole, or in participation with the railroads, to deliver the services to the railroads and others as a commercial enterprise.

As to the other wireless corridors that were identified earlier, there is one particularly interesting approach that is being pursued for the intra-train environment. This is the use of a wireless mesh network[†] throughout the train. A key design factor here is that of evolutionary deployment again. That is, this technology does not require each car in the train to be equipped with the technology. Instead, the low-power, wireless-based, sensor nodes, a.k.a. motes, can be installed on cars as deemed appropriate with their connectivity being coordinated via a gateway, i.e., a network controller that then can interchange data with off-board wireless networks.

Management Systems

The deployment of wireless data infrastructure doesn't mean that the current management systems and business processes will be able to use that data effectively. This is the next challenge to providing *evolutionary* versus *revolutionary* deployment that can deliver value immediately; value that might not have been achievable otherwise. Indeed, revolutionary changes in business processes may be perceived to be too difficult to implement or to have insufficient benefits to justify revolutionary changes in the IT and communication infrastructure. This is especially true for railroads in general where the primary business processes have changed relatively little in decades. Arguably, the ideal opportunity in the railroad environment is that of revolutionary change with evolutionary deployment, and that is very possible in a number of key areas. And, as identified in **FUNCTIONALITY**, there are those applications which are applicable to individual railroads as well as those that require access to resource status data from across the industry and, as such, have not been pursued due to do the lack of an industry-based infrastructure and data bases.

Recognizing which management services to begin with is actually quite simple, if one is willing to make cursory evaluations of two criteria that need to play well together in a wireless environment: value and data. As shown in the following matrix of these two parameters pitted against each other, there is an opportunity to define a deployment strategy that delivers high value, but with low data requirements first with some level of wireless data infrastructure (e.g., commercial services) and then progress to, or complement with, a more robust wireless data platform (e.g. a private wireless network). This movement from light to darker shaded blocks (upper right to lower left) is directly aligned with the discussion earlier regarding the Monitor vs. Mobile Platform corridors.

		VALUE		
		Low	Medium	High
DATA	Low	Wayside Maintenance	Crew Management Locomotive Management Locomotive Maintenance Remote Switch	Traffic Management Locomotive Fueling
	Medium	On Track Maintenance Threat Management	Yard Management Mobile Node Main-line Work Order Intermodal Services Passenger Services	P T C Traffic Control Flexible Block
	High	Moving Block - Eastern Railroads *		Moving Block - Western Railroads

* Eastern railroads expect little value from moving block due to the high density of contentious traffic.

Specifically, railroads could benefit immediately by having the simplest of wireless data systems that could then evolve in a financially responsible fashion. This is an approach that would include the shunning of installed technologies and implemented processes that were valuable at some point but that are no longer required. However, discarding installed equipment is a difficult concept for many to embrace in the industry even though the rapid changes in wireless and related technologies have, and will most likely continue to, provide valuable functionality. As such, those technologies may not be deployed due to the inability to discard the equipment of previous investments, even though the payback period has been well exceeded.

IT Architecture

Not inherent in the distributed, fixed node or centralized IT platforms in use by railroads today are the parameters of positioning and speed. The resources being managed by those platforms either don't move, or if they do, then their management process progresses in a discrete fashion throughout the sequence of fixed nodes or in-frequent update reports. This is the case with current traffic management in the railroads based upon the SCADA, CAD-signaling platform with trains advancing on a block by block basis with no indication of speed (as in, did the train stop?). This lack of visibility as to interim train status has contributed substantially to the current reactive (crisis-based) traffic management approach addressed in **FUNCTIONALITY**. Therefore, moving forward with location-based systems requires changes to the IT architectures in the railroads, both individually and from an industry perspective. There are 4 major considerations to make those changes.

1. Moving forward with wireless-based systems relative to proactive management of mobile resources can greatly benefit by the availability of a positioning platform, a *positioning engine*, that is tightly integrated with the IT

architecture. This is a platform that merges the various sources of positioning data into a single data domain that services all applications requiring such data. Those data sources would include direct reports via wireless, AEI, voice messages, EDI, OS reports, lineup entries, and the handling of authorities in dark territory. At least one railroad is known to have developed such a Kalman filter -like[†] approach.

2. Given the levels of operability identified earlier, the issue of positioning being incorporated into the IT architecture is not confined to each railroad addressing its own singular requirements. Positioning also has an industry perspective, as well as a cross industry and global perspective, depending upon the resource. For locomotives, obtaining positioning information today, whether on or off the owning/leasing railroad's property, varies greatly by railroad with a number of different sources as noted above. Reportedly, a significant amount of this information is not being shared between railroads for competitive reasons when associated with train consist data.
3. Associated with each perspective of positioning is the necessity for a common referencing system, a Geographical Information System (GIS), that ensures that each positioning reference is interpreted by all in the same way. While each railroad has greatly expanded the sophistication of their individual GIS platform and associated data within the last 5-10 years for their own reasons, each effort has been done without an industry perspective. Additionally, there has been no sponsorship at the industry level to assure compatibility, yet alone host an industry-level GIS platform, e.g., a Railroad Transportation GIS Model, as exists in other industries.
4. Recognizing the in-time & exception aspects of position reporting, instead of continuous real time based upon the resource involved, a concept of geo-fencing is becoming increasingly important. As introduced earlier, this is the ability to have a location-based system take some action when a geographical boundary defined in the positioning platform is crossed. For example, a locomotive could report its fuel level when it crosses railroad boundaries. As with the GIS requirement, there are different levels of geo-fencing opportunities, e.g., mobile platform, individual railroad, and industry.

Together, the levels of operability and the selective availability of data, along with the multiple levels of GIS and geo-fencing, demonstrates the need for a hierarchy of positioning platforms that can be used on a selective basis by authorized users (subscribers) independent of the providers (publishers) of the data. This publish / subscribe (pubsub)[†] concept is a key IT design perspective in assuring data accuracy and consistency across the enterprise and industry. It can minimize the duplication of data collection and storage in lieu of the isolated, self-contained model of traditional application development.

SCENARIO

Having identified the deployment issues of wireless coverage & throughput, the wireless environment, management services, and IT architecture, a possible scenario is provided below on how the railroads can advance a number of the opportunities identified in **FUNCTIONALITY** in a pragmatic and/or evolutionary fashion. It all begins with the deployment of a monitor platform on all locomotives for an individual railroad and finishes with an industry perspective.

I. Monitor Platform

While the industry proceeds to work through the development of a sophisticated mobile platform that will service the long term perspective of interoperability, there is a great deal of business value that is not being taken advantage of as noted in this report. Additionally, once the futuristic platform is available, there will be a substantial amount of time involved in building the management systems that can use the data. What is not being considered by most of the railroads, and clearly not at the industry level, is an interim solution that can deliver advanced functionality sooner instead of later, a solution that disrupts the tool/data Catch 22 to get the railroads moving forward with advanced functionality as described in this report.

By placing on-board each locomotive now a simple GPS-based, position/speed reporting unit that can provide information every 5-15 minutes along the main line (for example, an inexpensive unit using commercial services), a railroad will have the opportunity to begin the development of the evolutionary management systems (described below) to deliver the range of benefits associated with proactive asset management. And, with just a modicum of additional capability of reporting key locomotive health and fuel data, along with geo-fencing, the business values associated with the full locomotive application suite are obtainable. This is a platform that need not be uniform across the industry as to the equipment, message sets, or even protocol. But, it will be uniform as to the minimum reporting requirements as to exception and/or time intervals for various applications - thereby expanding beyond interoperability to address industry intraoperability. Reportedly, several roads have priced out commercial services for an increased frequency of reporting, and they have been disappointed by the cost of the offerings. But, if done as an industry, including the requirements for Amtrak, against a number of suppliers, in concert with a business case built on the business values identified in this study, it is believed that such an interim approach will have substantial net value. It is important to keep in mind that the requirements for such a platform are neither safety critical nor of significant throughput to be subjected to the reliability issues that have discouraged some railroads from considering cellular systems to date.

Some railroads already have the beginnings of reporting locomotive speed and position with either a private wireless network or the deployment of on-board communication /

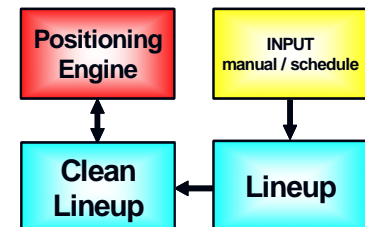
intelligence platforms, but no railroad was found to have put together the evolutionary perspective that follows below in delivering the business value, a perspective that begins with a *positioning engine*.

II. Railroad Positioning Engine

Again, the proactive management of a railroad's major mobile resources begins with knowing the position and speed of the locomotives, and there are a number of sources for positioning information. Currently, the railroads collect locomotive position, either directly or indirectly, by numerous means including commercial wireless services, AEI reports, OS reports (as to train movement), voice communications, lineup entries, and generation of authorities in dark territory. The accuracy and timeliness of these reports as well as where and how they are maintained by their respective users vary substantially. Most importantly, none of them are of sufficient timeliness, if even accuracy, to be used for proactive traffic management, and none of them provide speed information. However, they do have some value in servicing other applications, especially if a pubsub- based positioning engine is established that incorporates geo-fencing. With the development of such a platform that incorporates the appropriate data from the Monitor platform, a platform that is outboard of current systems, the next step becomes that of cleaning up the lineup.

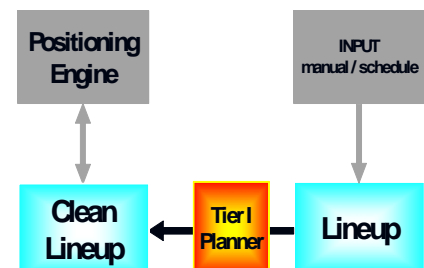
III. Cleanup the Lineup

A railroad's lineup that is an integral part of the CAD platform is typically fraught with errors and poorly managed due to the lack of timely data and the tools to manage the data. However, with the matching of the lineup against the positioning engine, the lineup can be cleaned up and made available to proactive resource management systems that are outboard of CAD.

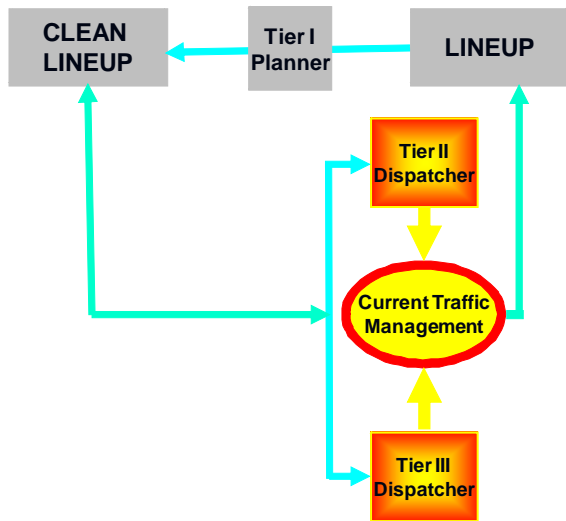


IV. Manage the Lineup

Cleaning up the lineup is not the same as managing the lineup. The former is that of continuously updating the true position of trains that have been initiated on the lineup. To manage the lineup, however, is the ability to bring planning tools into play that can project how the lineup will be changing over some period of the future. This means incorporating what is shown here to be a Tier 1 planner that is used by Operations management to align unscheduled and scheduled operations and account for physical network parameters, physical train performance, basic crew management rules, locomotive power requirements, and in-bound capacities of yards.



V. Proactive Traffic Management

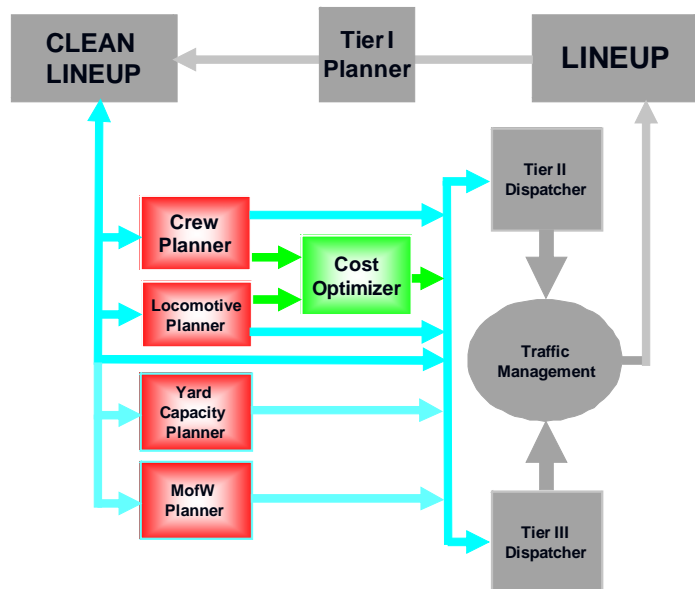


With the availability of a clean, managed lineup that is as timely as the most recent position report, whether it be an AEI report or via the Monitor Platform, a proactive traffic management system can be provided to the dispatcher independent of, but complementing, the CAD platform. That is, this platform will provide various levels of planning tools that permit the dispatcher to perform advanced traffic management analysis on an as-needed basis. For example, the dispatcher could have two levels of planning tools. Tier II would be used for a true-crisis solution that strives for a workable, but not

necessarily optimal solution in pressing situations. There would also be a Tier III planning tool to be used to meet the objectives of proactive traffic management. Again, for a scheduled railroad, the objective would simply be that of getting back to schedule. Once the dispatcher has determined the proper course of action, s/he would then use the CAD platform as is done today to set up the routing accordingly. At some point, there could also be an integration of the planning capability directly into the auto-routing[†] mechanism of CAD, if deemed appropriate.

VI. Proactive Resource Management

Expanding upon the above approach for traffic management, it is possible to advance the planning of other key resources, as well as incorporate their management within the dispatching function. Two of the resources, crews and locomotives, have direct costs associated with their deployment alternatives. As such, a cost optimizing function is added for the dispatcher to balance those costs with those associate with train movements, e.g., delay train, fuel consumption. Two other resources, yard availability and maintenance of way activity are



constraints that are used by the Tier II and III planners in deciding the routing of trains. As with Proactive Traffic Management, each of these could be maintained independent of, but complementary to, their respective current processes and management systems.

VII. Industry Locomotive Tracking System

If railroads were self-contained, then the structures presented above for this scenario would be sufficient to optimize their individual performance. However, there are challenges as to interoperability and industry intraoperability for both traffic management and the suite of locomotive applications, at least. Recognizing that the threshold unit of tracking is the locomotive, then there is a requirement for an Industry Locomotive Tracking System, as well as the positioning engines for individual railroads, to service these levels of operability. As noted earlier, there is an excellent way to move forward with that possibility now given the development of the EMIS system via Railinc's services. But, there will be a requirement in the railroad's interchange rules that require locomotive activity to not only be reported (which isn't required today), but also be required to provide a certain level of report frequency as to both position and speed.

What is interesting about this point, is that locomotive positioning could be achieved in two different fashions. First, there would be a continuous link between the Industry Locomotive Tracking System and the individual railroad positioning engines. Additionally, to the benefit of everyone, the use of commercial services that a railroad may employ for locomotive tracking could feed this data as well to the industry positioning engine, instead of to only the subscribing railroad. The Industry Locomotive Tracking System thereby becomes the clearing house for this information for the benefit of all.

The Industry Locomotive Tracking System avoids the current issue of the privacy of consist data by means of the pubsub structure that restricts the accessibility of specific data to subscribers with the proper authority while blocking associated data that is not to be distributed to those same parties.

VIII. Industry Service Bus

It is a small step to morph the Industry Locomotive Tracking System into an Industry Service Bus that can service a number of applications including locomotive health, hazmat alerts, shipment integrity, and fuel management. Associated with this approach would be an appropriate level of GIS as well as geo-fencing relative to the industry issues for which this tracking system would be used, e.g., interchange points for fuel level determination.

SKILL SETS

To effectively deploy wireless-based applications requires three types of skill sets, three types of disciplines, of which only two can be expected to be found today in the railroads and at the industry level via the AAR and its various committees.

First, there is the requirement for the *Technicians* within each railroad that understand the capabilities of the wireless technologies that may be deployed. As such, each road has its technical staffs from which the respective AAR technical committees are staffed on a volunteer basis.

Second, recognizing that wireless can extend the IT architecture to the mobile and remote resources, as wired infrastructure does in a manufacturing facility, then wireless needs to be incorporated in a compatible fashion with the IT architecture. Fortunately, within the last several years there has been a concerted effort to merge the two disciplines of wireless and IT together both within the individual railroads and within the AAR technical committees to expand the role of the *Enterprise Architect*[†] that aligns the IT architecture with the business requirements.

Third, with the infusion of wireless data into the railroad environment, the current Enterprise Architect discipline is unprepared and for justifiable reasons. That is, the current railroad IT architecture is typically structured to service primary business processes that have existed for decades based upon technologies that stem back to the 1st and 2nd quarters of the last century, i.e., track circuits and voice radio respectively. Hence, these key business processes and the supporting management systems are so geared as to a certain level of data timeliness and accuracy that are less than optimal. However, with the deployment of a wireless data infrastructure, in-time data as to the status of resources is introduced. This infusion presents the opportunity for a *revolutionary* change in the business processes across the individual railroad as well as across the industry. These are changes that can incorporate planning and execution tools that embrace a wider range of variables, with a greater level of accuracy and detail, than that which is possible of being done today. Accordingly, these are changes that are likely to be beyond the experience and knowledge of Enterprise Architects that have operated primarily in a wired environment and/or who have been subject to the constraints of the railroad's traditional technologies. Hence, there is a requirement for a new discipline, i.e., an *Enterprise Technologist*.

The Enterprise Technologist is a discipline that is focused on a revolutionary re-engineering of business processes across the railroad that can include

- distributed intelligence to the mobile resources as an extension of the IT architecture, a.k.a. a mobile node,

- the use of Operations Research (OR)-based execution and planning tools,
- the establishment of new voice/data links between otherwise-disparate entities, and
- the integration of the management of remote and mobile resources.

However, revolutionary functionality is without value if it cannot be delivered in a fashion that is financially, organizationally, and technically responsible. This leads to the second role of the Enterprise Technologist, i.e., the challenge of evolutionary deployment. Such a deployment is necessary given a railroad's extensive physical plant and IT architecture that is well established and not readily modified, yet alone replaced. This is a discipline that structures the business case that includes

- 80/20, incremental value / cost analysis,
- phased deployment based upon payback analysis,
- multi-department infrastructure sharing, and
- the recognition that Refarming has changed the business case model.

At first glance, it may seem that the Enterprise Technologist's tasks are not unlike that of the traditional Six Sigma process referred to as Define-Measure-Analyze-Improve-Control (DMAIC). However, DMAIC Six Sigma focuses on evolutionary, continuous improvement of existing processes. That is not the case for what is presented in this report, i.e., the revolutionary change in processes albeit via evolutionary deployment of management systems. In actuality, the Enterprise Technologist, is quite similar to an emerging discipline in Six Sigma referred to as Design for Six Sigma (DFSS). A key difference remains in any event, and that is the ability to deliver the business case aligned with the revolutionary changes in functionality, both at the individual railroad level and for the industry given the various levels of operability.

MOVING FORWARD

Based upon the findings of this study, there are a number of activities that would promote the advancement of rail operations, via the use of wireless technologies that are not being pursued by either the industry or most if any of the railroads. These are activities that would complement the current Roadmap to Interoperability and associated tasks currently underway. These are activities that would benefit by the availability of Federal support.

Traffic Management Tools & Processes

Most North American railroads have little to no experience with traffic management tools in general, and certainly not with those based upon timely position and speed data as discussed in this report. Developing and deploying such tools will be a blending of art and

science given the lack of experience and data that exist to identify the key variables and the primary objective functions that can be delivered through their use. And, there is both a planning (Service Design) and an execution (Operations-dispatching) aspect to these tools that should be considered. Hence, there is a need to perform the following analyses that would be applicable across all Class I railroads.

- A. the coordination of traffic management activities between Service Design and Operations;
- B. the identification of different tiers of dispatching tools as suggested in **SCENARIO**;
- C. the identification of dispatching processes and displays to support the use of traffic management tools;
- D. the study of interchange requirements to efficiently support the use of traffic management tools.

Locomotive Position and Status

An Industry Locomotive Tracking System has substantial value for both the freight railroads and Amtrak. Railinc appears to be in a favorable position to deliver such a data service to the industry. However, the analysis still needs to be performed as to what data are needed when and where not only as to locomotive position and speed but also as to diagnostics and fuel. This would include the identification of geo-fencing criteria at three primary platform levels, i.e., mobile node, individual railroad office, and industry.

Performance-Based Locomotive Maintenance

As was done with PTC, there is an opportunity to have a RSAC or similar process associated with performance-based maintenance of locomotives based upon the availability of an Industry Locomotive Tracking System that included health and maintenance data.

Train Position Monitoring

On-line maintenance crews could benefit from the availability of train position monitoring available via an Industry Locomotive Tracking System. Such a capability could complement if not replace the current use of watchmen lookouts where currently required today.

Crew Management

Railroads and their train crews could benefit from the use of crew management tools. These are tools that can improve both the efficiency of crew usage as well as the quality of life by minimizing non-productive crew usage, e.g., deadheading, held away, etc. While there has been some pursuit of such tools, they require further refinement and the opportunity to be deployed.

Industry GIS Model

The industry could benefit from a concerted effort to identify an uniform, rail industry GIS model. This is a model that may need to be aligned with similar efforts in other industries, e.g., utilities, petro-chemical, etc.

Performance-Based Wayside Maintenance

As was done with PTC, there is an opportunity to have a RSAC or similar process associated with performance-based maintenance of signaling infrastructure based upon a TBD level of monitoring and diagnostics reporting.

Mobile Node

The railroads' primary focus on the on-board intelligence and communication platform has been that of interoperability and safety given the interest in PTC and one-person crews. There has been some activity relative to expanding the functionality of the mobile node relative to intra-train operability. However, there remains the broader philosophical, functional, and strategic perspective of the mobile node as an extension of the IT platform.

Evolutionary Wireless Strategy

While the railroads' technicians and enterprise architects pursue the interoperable mobile platform and associated VHF refarming challenge, the opportunity exists to develop an evolutionary wireless strategy that can deliver substantial benefits in the interim. This approach involves the *enterprise technologist* discipline, as defined above, in lieu of just technicians and architects, to produce a business strategy aligned with an elementary wireless approach.

Operability

The challenge of operability is substantially greater than that of railroad intraoperability and interoperability as is being currently addressed across the industry. The other levels as identified in this report need to be addressed as well as to the areas of functionality, data flows, and supporting infrastructure. Such a pursuit is as much functional as it is technical, with a touch of intra & inter industry politics.

Homeland Security

The response to 911 by the Class I's was immediate and responsible. A renewed effort may be appropriate, however, with an expanded understanding of what a wireless data infrastructure(s) can now provide that was not available at the time of the initial effort.

CLOSING COMMENT

This study was not designed to be all-inclusive of the opportunities for wireless technologies in high speed passenger and freight rail. Instead, it was structured to seek out the incremental opportunities and the means to deliver those opportunities given the individual and collective railroad agendas as to functionality and wireless technologies. The bottom line for this study is exactly that, i.e., identify the opportunity to deliver the business case that demonstrates the value of moving forward now, both at the individual railroad and industry level, with systems that deliver tremendous value while the industry continues to work on the long term visions. And, to do so takes a new discipline of the Enterprise Technologist that complements the efforts of the technicians and enterprise architects for the railroads, both individually and collectively.

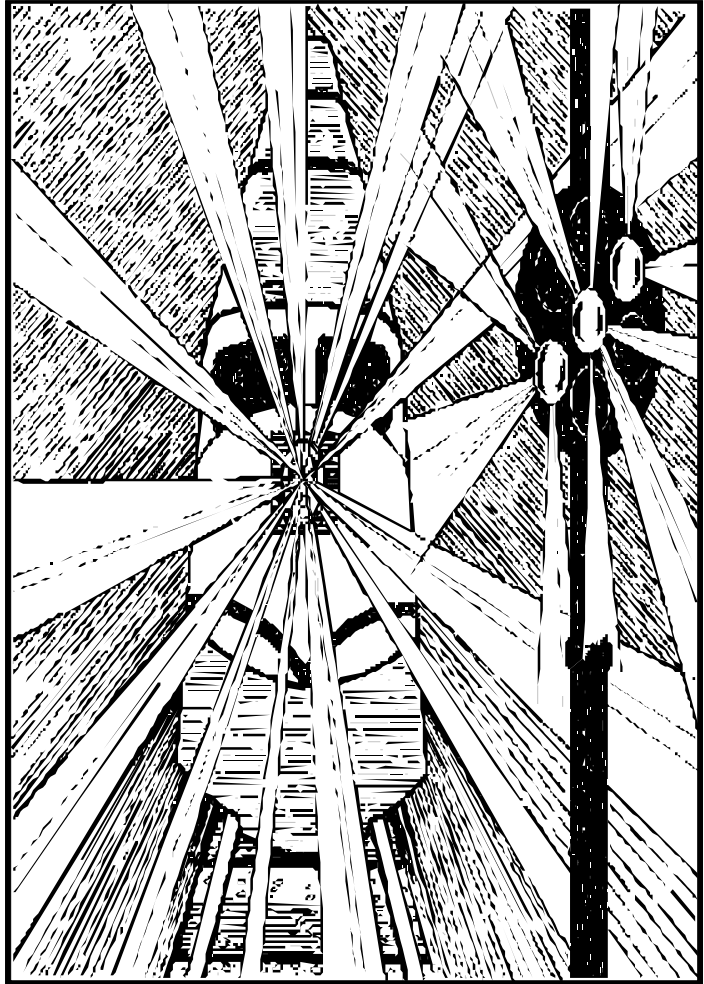
APPENDIX: Description of Terms & Phrases

A E I	Automatic Equipment Identification: the passive RF tag and interrogator infrastructure that is used to identify cars and locomotives when they pass an interrogator. There are approximately 1.3 million rail cars and locomotives that have been tagged in North America.
AAR	Association of American Railroads: Industry association for the Class I railroads
Autorouting	a process built into some CAD systems that permits the dispatcher to set up routing for trains that will align the switches automatically as the train progresses based upon a relatively simple priority basis.
Book of Rules	the underlying rules for on-track operations - the passive vitality of railroad operations.
C A D	Computer Assisted Dispatching: the platform that permits the dispatcher to request routing for trains.
Code Line	the non-vital communication link between CAD and the wayside signaling infrastructure that permits the train dispatcher to make requests of the vital wayside infrastructure to route trains as well as provide indication of wayside signals - a SCADA platform .
Critical Infrastructure	“those physical and cyber-based systems essential to the minimum operations of the economy and government. They include, but are not limited to, telecommunications, energy, banking and finance, transportation, water systems and emergency services, both governmental and private.” (Source: Presidential Decision Directive NSC-63.)
E D I	Electronic Data Interchange: A set of standards for structuring information that is to be electronically exchanged between and within businesses, organizations, government entities and other groups.(Source: Wikipedia)
ECP Brakes	Electronically Control Pneumatic Brakes: the use of a wired connection running through the train that activates each car’s brakes simultaneously.
Enterprise Architect	a discipline that “build(s) a holistic view of the organization's strategy, processes, information, and information technology assets ... (so as to) take this knowledge and ensure that the business and IT are in alignment. The enterprise architect links the business mission, strategy, and processes of an organization to its IT strategy, and documents this using multiple architectural models or views that show how the current and future needs of an organization will be met in an efficient, sustainable, agile, and adaptable manner.” (Source: Wikipedia)
Kalman filter	an efficient recursive filter that estimates the state of a dynamic system from a series of incomplete and noisy measurements. It was developed by Rudolf Kalman. (Source: Wikipedia)
Lineup	the listing of trains that are expected to operate over a railroad’s territory within the railroad’s operation horizon.

Meet / Pass Planner	a set of mathematical algorithms that is used to optimize the objectives of traffic management selected by a railroad for its operation.
Movement Authority	the permission provided to a train crew to advance the train as to distance, speed, and/or time. In signaled territory, the movement authority is provided as an aspect (a configuration of lights) that indicates permission to proceed and speed restriction. In dark territory, the authority is transmitted by the train dispatcher to the train crew.
Non-Signaled Territory	a method of train operation in which the primary authority is generated by a manual process(train sheet) or a computerized conflict checker. The transmission of the authority to the train crew is done by the train dispatcher. There are two types of dark territory. One in which there are no signals (most common). The second type, known as Absolute Manual Block, incorporates signals in the territory, but the signals only provide a secondary level of authority within the primary authority, and their aspects are not provided to the dispatcher.
OS Reports	the (On Station) indications of a train entering a new control point in signaled territory.
Positive Train Control	a system that is used to prevent train crew errors. There are 3 core objectives of PTC. 1. prevent train to train accidents, 2. prevent trains from over-speeding, an 3. prevent trains from endangering work gangs. An overlay PTC system is one which does not affect the method of operation, meaning that it is not vital.
PTC capital investment	On its own, PTC is a locomotive-centric application, which by design requires only the transmission of information to the train, and not visa versa. Hence, designing a wireless network for PTC does not mean that the network would be capable of applications that are office-centric, e.g., traffic, locomotive, or fuel management.
Publish Subscribe	Publish/subscribe (or pub/sub) is an asynchronous messaging paradigm where senders (publishers) of messages are not programmed to send their messages to specific receivers (subscribers). Rather, published messages are characterized into classes, without knowledge of what (if any) subscribers there may be. Subscribers express interest in one or more classes, and only receive messages that are of interest, without knowledge of what (if any) publishers there are. This decoupling of publishers and subscribers can allow for greater scalability and a more dynamic network topology. (Source: Wikipedia)
R C L	Remote Control Locomotive: a wireless application that permits an individual on the ground to move a locomotive. This application is used for switching in yards. This should not be confused with pursuit of one-person crews which involves main line operations.

RSAC - PTC	Railroad Safety Advisory Committee - PTC: a joint effort by the FRA, railroads, and labor as voting participants to define a possible rulemaking relative to PTC as well as to evaluate the safety case for PTC. Suppliers also participated, but without voting rights. The PTC rulemaking was a direct result of this effort.
S C A D A	Supervisory Control and Data Acquisition: "system that is placed on top of a real-time control system to control a process that is external to the SCADA system (i.e. a computer, by itself, is not a SCADA system even though it controls its own power consumption and cooling). This implies that the system is not critical to control the process in real time, as there is a separate or integrated real-time automated control system that can respond quickly enough to compensate for process changes within the time constants of the process. The process can be industrial, infrastructure or facility..." (Source: Wikipedia)
Toxic Inhalation Hazard	the transportation of chemicals that when inhaled can cause hazards to living organisms.
Traffic Management	the management of the traffic control process to meet a railroad's objectives for the movement of trains. This is the true purpose of the train dispatcher.
Track Circuits	a DC circuit that runs through the rails. When a vehicle (locomotive) enters a segment of track circuit (block) and shunts the circuits between the rails, then the signaling infrastructure generates aspects based upon the block being occupied.
Traffic Control	the process that generates movement authorities that thereby is the vitality of rail operations. This is not what the dispatcher does directly, but is what s/he often initiates in the traffic management process.
Train Control	the handling of the train by the train crew. This phrase is often used mistakenly to refer to traffic control.
VHF Refarming	a.k.a. narrow-banding, a FCC Point & Order to split the frequencies in half in a portion of the VHF by 2013. An additional Point & Order was issued in March 2007 to note that the same channels would be split again at some point, but no date was provided.
Vitality	From a safety design perspective, vitality means that the device / system will fail safely, i.e., with no increase in risk. From a railroad operation standpoint, vitality refers to the functionality of the hardware and/or software that generates movement authorities that provides for the integrity of train movements.
Wireless Mesh	"a wireless cooperative communication infrastructure among a massive number of individual wireless transceivers (i.e. a wireless mesh) that has a network routing capability. Mesh networks are self-healing: the network can still operate even when a node breaks down or a connection goes bad. As a result, a very reliable network is formed. This concept is applicable to wireless networks, wired networks, and software interaction. "(Source: Wikipedia)

Wireless for Railroads



The primary operating practices of freight railroads have changed little in nearly a century given the dependence upon traditional technologies. Now with the availability of wireless data networks in concert with advanced management systems, railroads can make a paradigm shift in their processes to optimize the efficiency of their extensive key operating resources including track time, locomotives, yards, and crews. Additionally, the expanded use of wireless technologies can support the tighter integration of operations between freight and passenger railroads, other transport modes, and public safety.

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* Railroad-ese when first used in this document is in *italics* and defined either in the text or the GLOSSARY

Wireless for Railroads

PURPOSE

This paper addresses the extraordinary opportunities railroads have, both individually and collectively as an industry, to advance their operations via the use of advanced wireless technologies, as well as to improve the efficiency of their spectrum usage. This perspective is expanded to consider the relationship of the freight rail industry with passenger rail, other transportation modes, and the intersection with public safety. This is a **STRATEGIC PERSPECTIVE** based upon identifying both the **DEMAND** for and **SUPPLY** of wireless technologies which provides the basis for structuring an approach for **MOVING FORWARD**.

BACKGROUND

Since the 1st and 2nd quarter of the last century, North American railroads have depended upon two primary technology platforms for managing the safe movement of their trains, i.e. *signaling traffic control systems* (a railroad's traffic lights) and analog wireless voice communications respectively. As such, the railroads have been constrained as to the level of efficiency of traffic movements that they can achieve due to the use of traditional management processes based upon the two technology platforms. However, the tremendous increase in rail traffic over the past decade, especially with the advancement of *intermodal* operations, is pressing the railroads to provide additional capacity, for which they have two primary alternatives. That is, they can take the traditional approach of making substantial investment in additional track infrastructure and related resources, and/or, as will be addressed in this document, they can use wireless data networks and management systems to significantly improve both the safety and efficiency of their operations, thereby minimizing the capital investment for additional resources.

Given both the traditional processes of railroads as well as the substantial investment in analog wireless infrastructure, the railroads have been reluctant overall to take on revolutionary changes to operating practices. It has only been within the last several years

that two *Class I* railroads in particular have incorporated advanced traffic planning tools into the dispatching operation, an improvement that is primarily due to the availability of wireless data networks, both commercial and private. Simply stated, wireless data networks offer the railroads the opportunity to make a major paradigm shift in managing their key operational resources in a *proactive* fashion [1]. The underlying logic is straightforward.

- The more timely the status of assets are known (to a point), then the better the assets can be managed.
- And since a railroad's primary assets are mobile, then wireless data systems are required to obtain those timely data.

While each railroad could advance a wireless data platform for its individual use, and several have, there is also an industry perspective given the substantial interchange of trains between railroads. Similarly, there has been relatively little consideration by the freight railroads as to the use of wireless relative to their interactions with other transport modes as well as with public safety.

Given the above, the railroads could benefit from a comprehensive understanding of what can be done (**DEMAND**) with wireless data networks given both current and advancing wireless technologies (**SUPPLY**). One methodology to do so will be addressed in this report in **MOVING FORWARD**.

DEMAND ¹

Railroads have used wireless, radio frequencies (RF), for communications since the 2nd Qtr of the last century. Initially, wireless networks were set up along a railroad's main tracks, a.k.a. *main line*, for voice communications so as to eliminate the *dispatcher* telephone line mounted on *pole lines*. This permitted a train crew to talk to dispatchers to receive *movement authorities* to advance the train without stopping the train to use a wayside telephone. As such, the use of wireless along the main line requires only a few channels in any given geographical area to handle a low level of voice communications. Additionally, wireless voice became the chief means to coordinate activities within and between crews within railroad yards. However, unlike main line operations, each yard crew is assigned a dedicated channel for safety purposes. Therefore, with a heavy congestion of trains and yards in major metropolitan areas, the coordination between railroads of less than 100 channels in the 160-162 MHz band licensed to railroads has been an extremely difficult balancing act. This latter situation has given many the impression that the band is heavy congested across the industry, which in fact it really isn't especially if proper technologies were used, as addressed later. In either situation, main line or yard usage, the effective use of the 160-162 MHz band spectrum in terms of transmission versus available time continues to be quite low given the lack of significant wireless voice traffic across the railroad overall.

It has only been in the last two decades that wireless data has been used by railroads for communication between devices to complement the voice communications for personnel. In general, such efforts to date have loosely been referred to as *Intelligent Railroad Systems*, with most being pursued on an individual railroad basis

without any coordination across the industry. The first such use across the industry was that of end-of-train (EOT), a radio telemetry solution in the 450 MHz band that was initially used to permit the engineer (train operator) to monitor the *brake line* air pressure at the end of the train, thereby eliminating the requirement for cabooses. Subsequently, EOT was expanded to permit the engineer in the locomotive to release the air pressure at the end of the train in addition to the release from the locomotive for more uniform emergency braking.

Following EOT, railroads have utilized wireless data networks, both private (220, 450, & 900 MHz bands) and commercial, for singular applications such as monitoring locomotive diagnostics, downloading data from the locomotive's event recorder (a locomotive's black box), remotely controlling locomotives (*RCL*) in a yard, and replacing the *code line* on the pole line so as to eliminate the need for such infrastructure subject to extreme weather such as tornadoes and ice storms. One of the results of the deployment of singular wireless-based applications over the years is a complex wireless environment on board the locomotive that may have up to 14 antennas on its roof to handle the variety of wireless-based applications. Such a configuration is evidence of duplicate RF coverage due to individual departments within a railroad pursuing their individual applications with individual wireless paths.

With the intent of breaking away from the singular problem / singular solution approach to implementing wireless-based applications, two significant efforts have been performed in

¹ Callouts are used in this segment to note the highlights shown at the end of DEMAND

the past 15 years to define the opportunity for improving the use of wireless spectrum and technologies by freight railroads. The first effort in 1996, coordinated by the *American Association of Railroads (AAR)* and facilitated by IBM, was a review of the primary operating processes used by a railroad and determining whether or not wireless could be of benefit. A year later this study was expanded in context by IBM by applying *Business System Planning (BSP)* techniques to define an information flow architecture within a generic railroad. Dubbed the **Demand Study**, the AAR was able to use this report in its subsequent discussions with the Federal Communications Commission (FCC) in justifying the industry's RF requirements at that time[2].

The second effort to define the opportunity for wireless was a study that was performed 3 years ago. Sponsored by the Federal Railroad Administration (FRA), this study was more strategic and functional than structural as with the 1996 study. Titled "An Analysis of the Opportunities for Wireless Technologies in Passenger and Freight Rail Operations", the study involved railroads and suppliers alike, both individually and collectively, in a series of interviews and work sessions to identify and describe specific advancements in freight rail operations that could be made with wireless technologies [3]. As informative as the study was in identifying and describing the opportunities for wireless, it also expanded the boundaries of operability, theretofore viewed only as *railroad interoperability*, i.e., the ability of a train to cross railroad boundaries without a loss in functionality. Understanding additional levels of operability is critical not only as to improving the capability of the rail industry overall, but also in defining the type of wireless technologies and spectrum that can be used. Hence, the remainder of this DEMAND section highlights both the **Opportunities** to advance rail operations via wireless as well as describe the various levels of **Operability**.

Opportunities

The opportunities for advancing rail operations via wireless systems can be viewed as to 5 primary objectives: 1. Increase traffic velocity, 2. Optimize resource utilization, 3. Minimize maintenance costs, 4. Improve customer service, and 5. Ensure safety. Each of these is discussed below as to their respective opportunities.

Increase Traffic Velocity: Arguably, the most important objective for a Class I railroad currently is that of *traffic velocity*, i.e., the average rate of travel for trains across a railroad's infrastructure. The greater the velocity, then the greater the capacity that the railroad can handle with its given infrastructure, thereby offsetting or minimizing the investment in additional infrastructure. However, the railroads are now finding themselves constrained with their traditional technologies and associated operations processes to make any additional significant increases in velocity with their current infrastructure. To a great extent this is due to the fact that freight railroads effectively operate in a non-scheduled fashion given the continuous occurrence of conflicts in train movements. Such a *reactive traffic management* environment can be quite challenging in considering the number of parameters that are involved in coordinating train movements, including yard availability, train crew work limits, fueling, and opposing trains on single tracks.

With the use of wireless data networks, timely and accurate train speed and position data can be obtained and fed to mathematical planners that can optimize the performance of such parameters. That is, railroads can make the transition from reactive traffic management to *proactive traffic management (PTM)* where forthcoming conflicts are projected by means of *mathematical planners* with solutions being

provided to the *dispatcher* to minimize consequences, if not avoid the conflicts altogether [1]. What is most interesting is that such a transition can be made with relatively little investment and delay. Specifically, the reporting frequency of position and speed data required to use the mathematical planners adequately is no more frequent than every 5 minutes, thereby negating the need for a sophisticated wireless network. Additionally, the mathematical planners can be provided without modifying or replacing a railroad's current computer assisted dispatching (CAD) platform. 5

It should be noted that the value of PTM operations diminishes as a railroad increases its degree of truly scheduled operation. However, given the substantial interchange of trains between railroads, the ability to run to a true schedule for any one railroad relative to that type of traffic is subject to the schedule efficiencies of the roads with which it interchanges. Unlike the passenger airlines that can operate to schedule without concern about other airlines, running a truly scheduled railroad operation requires the appropriate management mindset and commitment from across the industry. Without such a commitment, PTM offers the best opportunity for an individual railroad to optimize its performance. 6

Optimize Resource Utilization: While track time can be best managed via PTM, as measured by traffic velocity, there are other primary resources that can be better managed with availability of more timely status data as well. The most important assets across the industry are train crews, locomotives, yard availability, critical rolling stock, and fuel. However, the efficient management of all of these is dependent upon the efficiency of train movements, and the more unscheduled the trains are, the greater the inefficiency of the resources. Specifically, in unscheduled operations where temporary, local shortages occur due the lack of predictability of where resources will be at any given time, a railroad compensates by deploying excess (*slack*) resources to ensure that 7

trains can operate. Such *unstructured* inefficiencies can be significantly high. Even in truly scheduled operations, extra resources are deployed as well. However, these *structured* inefficiencies are less costly, more efficient, than the unstructured inefficiencies of non-scheduled operations.

Minimize Maintenance Costs: Much of a railroad's critical infrastructure and equipment is subjected to strict regulatory maintenance practices developed and enforced by the Federal Railroad Administration (FRA), including grade crossing systems, locomotives, and signaling infrastructure. With the advancement of electronics, the operation of many of these remote or mobile equipment and systems has become increasingly reliable. However, to a great extent they are still subject to *prescriptive* practices that outline temporal parameters for inspections and repairs regardless of the actual condition of the equipment and components. Such inspection requirements are extremely costly and too often unnecessary except for the practice of it being better to be safe than sorry. With the use of wireless technologies, there is the opportunity to move to *performance-based* maintenance where remote or mobile equipment and components can be monitored as to their operational status with sufficient accuracy and predictability to initiate maintenance activity only when actually required. Additionally, with the availability of nationwide wireless coverage, then such performance-based maintenance can be provided for equipment regardless of where it is operating, most importantly the significant number of locomotives that operate over multiple railroads across the continent. 8

Improve Customer Service: In addition to the improvements in customer service that will result from railroads operating more efficiently and reliably as to schedule, shippers can benefit directly from the use of wireless. Specifically, wireless can provide for direct 9

monitoring of shipments by shippers regardless of the railroad over which the cargo is traveling. Additionally, if permitted by the railroad, shippers can be in direct communications with train crews that are dropping off or picking up rail cars on an immediate basis, thereby avoiding the delays involved with traditional work order processes.

Ensure Safety: Ensuring the safety of the railroad has a wide spectrum of meaning, not the least of which is protecting employees, preventing train accidents, safe handling of hazardous material, and being proactive as to preventing possible terrorist activities. Wireless has, and continues to play an increasingly important role in these areas [4]. Examples follow:

- As noted earlier, railroads use traffic control systems to ensure the safe movement of trains. The two primary types of traffic control used by freight railroads, i.e., signaling and *non-signaling*, can benefit by the use of wireless data to improve both their availability and their efficiency of operations.
- In 2008 the Federal government mandated the deployment of enforcement system, generally referred to as *Positive Train Control* (PTC), before 2016 for most of the freight and passenger rail operations across the U.S. Via the use of wireless data and GPS positioning, PTC prevents train accidents due to operator errors. While the cost of implementing PTC relative to its value over the next 20 years is projected to be a ratio of 20 / 1 [11], the wireless data infrastructure being deployed could be used for other business applications, e.g. PTM. Additionally, PTC has the possibility of being used to balance the perceived or real safety issues with other changes in operating practices that can provide substantial business value, e.g., reduction to one-man crews. It should be noted that there are two primary types of PTC approaches that are significantly different from each other. One will be used by the freight railroads, and the other, *ACES*, will be used by Amtrak on the Northeast corridor (NEC)

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- Wireless data networks provide for the monitoring of critical shipments for domestic security purposes as to detecting tampering, tracking chain-of-custody, and providing timely location data. Additionally, wireless data networks are used for monitoring remote locations and critical structures as to security status and operating status.
- Wireless data networks provide connectivity for wayside sensing devices along the railroads' mainlines that are used to measure and report critical parameters of rolling stock, e.g., hot box heat detectors, dragging equipment, excessive shipment height, etc., thereby permitting the prevention of derailments and other dangerous occurrences.

Operability

Operability can be generally defined as the ability to operate in a desired fashion in a cost-effective fashion in various environments. Until the last decade, railroad operability was limited to *intraoperability*. That is, the engineering forces of the railroads were tasked with ensuring that whatever changes they made as to equipment, infrastructure, systems, and procedures could be handled across their specific railroad without undue consequences in performance or costs. Due to a Federal Communications Commission (FCC) rulemaking as to *narrowbanding* VHF, including the 160-162 MHz band used by railroads, the Class I railroads began addressing *railroad interoperability* (again, trains crossing railroad borders) from a wireless standpoint within the last decade. However, it wasn't until the Federal PTC mandate in 2008, that the Class I railroads took upon themselves to develop both technical and functional solutions to provide for the interoperability of PTC. Recognizing the complexity of the effort, it is not surprising that they have not considered the wireless requirements for interoperability on a broader business and boundary basis [5].

However, there are considerable reasons to do so, and for several different levels as described below.

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Industry INTRAoperability: With very few exceptions, railroad's have limited their use of technologies and the management of their mobile assets to their own property. Yet, there are valuable benefits to be achieved by providing for an *industry intraoperability* perspective, i.e., being able to track the status of mobile assets across the industry regardless of the property over which they are operating. Examples follow:

- Maintaining a thorough chain of custody for critical shipments;
- Knowing the operating condition of a *foreign locomotive* in the train;
- Knowing the fuel level of locomotives at interchange points;
- Being alerted as to the health of critical shipments throughout the trip;
- Having an accurate ETA for foreign trains approaching interchange;
- Permitting performance-based maintenance of locomotives in lieu of the current prescriptive based; and
- Establishing an industry-wide approach for locomotive maintenance and part warranty.

Cross industry operability: This level of operability brings the railroads in contact with other transportation modes as well as shippers. Consideration of such interaction started primarily with the initialization of *Intelligent Transportation Systems* (ITS) established by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). The importance of such interconnection was expanded as the result of 9/11 relative to domestic security, and more recently with the mandate of PTC in 2008 which requires interoperability between freight and passenger rail operations. This level of operability has the greatest challenges as to defining functionality, using spectrum, and applying technologies, and as such will be addressed below in **MOVING FORWARD**.

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Train INTRAoperability: What has yet to be fully appreciated, yet alone developed, are the requirements for communications within a train. As noted earlier, EOT was the first use of wireless data across the industry which provided the telemetry of information between the locomotive and the end of the train. Since then, *distributed power* has been used in select situations where locomotives are positioned mid-train to provide additional power in sync with the locomotives at the head of the train. Additionally, there are valuable opportunities for communicating between rail cars, shipments, and the locomotive as to conditions that might affect the health or safety of the operation.

Callouts: The following are summary points regarding the demand of wireless by the railroads as noted by call outs above.

1. The effective use of the railroad's 160-162 MHz band is quite low.
2. The singular pursuit of wireless applications has resulted in duplicate RF paths.
3. Railroad interoperability is the only level of operability being actively pursued.
4. PTM requires relatively little wireless data.
5. PTM does not require a new CAD platform.
6. Railroads are generally unscheduled.
7. Railroads employ excessive slack resources due to the lack of scheduled operations.
8. Wireless data offers the increased possibility for performance-based maintenance.
9. Wireless data offers new levels of customer service.
10. PTC is the impetus for the rail industry to actively pursue a wireless data network for the industry.
11. Industry intraoperability offers unique opportunities for advanced resource management that has yet to be recognized by railroads and suppliers.
12. BSP is one methodology for determining the opportunities to advance the use of wireless.

SUPPLY

As discussed above, the railroads have been using wireless for voice communications since the 1st half of the last century within the 160-162 MHz band. That band is subject to the FCC narrowband rulemaking that requires a substantial investment to replace the railroads' 250,000 radio units used in that band before 2013. Additionally the railroads have made substantial investments in two other bands, 450-460 MHz and 896-932 MHz, to support a few wireless data applications in the last two decades. All investments have been on an individual by individual railroad basis with frequencies coordinated via the AAR when necessary.

As to the replacement of the 160-162 MHz equipment, it should be noted that the railroads decided not to use technologies that could have substantially improved the poor efficiency of that band given the unique characteristics of its use along the mainline and in major metropolitan areas, as described earlier. Rather, several Class Is decided to acquire channels in the 220-222 MHz band to provide a new wireless data network in addition to the parallel 160-162 MHz network that could have supported substantial data and voice requirements if so equipped with proven technologies. Subsequently, with the PTC mandate, the Class Is elected to use the 220-222 MHz band for the first industry-wide network to provide interoperability. It should be noted that there was no regulatory requirement to use this or any other band for PTC. Aligned with this deployment, the major Class Is are designing their own high speed data radio platform.

In addition to the above wireless bands, one Class I railroad invested in a meteor burst platform that provides relatively inexpensive wireless data for both mobile to central office as well as peer-to-peer. That platform is now owned by the major Class Is, but without any

known usage planned across the industry, at least at this point given the concerted effort to deploy the spectrum in the 220 MHz range for PTC.

With parallel networks along the mainline and various wireless networks elsewhere, including unlicensed WiFi, there are current and advancing technologies from which the railroads could benefit as to improving the spectrum efficiency of the various networks as well as minimizing the investment and maintenance costs of deploying unnecessarily-duplicate RF coverage. Additionally, in consideration of the various levels of operability described in **DEMAND**, there is also the consideration of interfacing with other spectrum bands, whether current or additional, to address the voice and data interactions between railroads, other transport modes, and public safety. The most noticeable, achievable technologies for these purposes are *trunked radio*, *software defined radio (SDR)*, *cognitive radio (CR)*, and commercial services as described below.

Trunked Radio: Since the late 1970's trunked radio systems, a.k.a. Specialized Mobile Radio (SMR), have been used to optimize the efficiency of particular RF bands to service the business community. Compared to conventional radio systems that require the user to choose a particular channel over which to communicate, SMR uses computers and a control channel to dynamically assign currently-available channels to users when requested. A simple analogy is that of having one queue in a bank in which a bank employee sends the next customer to any available teller, instead of having a queue for each teller and the customers having to wait an unpredictable amount of time to move to the head of the queue. Hence, the use of trunked radio technology would be extremely effective for the 160-162 MHz band in major metropolitan areas where there are many users, but with each having only relatively quick and few conversations.

As mentioned earlier, the railroads elected not to pursue trunked radio to meet the FCC narrow-band mandate. At that point a number of years ago, the railroads seemingly believed that the available analog trunked radio technology would be too difficult to configure. However, with the advancement of digital trunked radio, the railroads still elected to not pursue the possibility. Instead, they elected to obtain and build a parallel network in the 220 MHz range, thereby continuing the inefficient conventional radio structure for the new digital 160-162 MHz infrastructure.

Software Defined Radio: With the term SDR being introduced in 1991, it can most simply be described as replacing a number of hardware components of a radio unit with software. The underlying principle for doing so is the use of some form of digital signaling processors (DSPs) that can replace specifically designed hardware such as RF filters, mixers, amplifiers, and modulators/demodulators[6]. While that sounds interesting, the real advantage is that a single signal processing platform can instantly switch between an unlimited number of combinations of bands and protocols (a.k.a. multi-band, multi-function) provided the software is made available. From a railroad's standpoint that means that a SDR-based locomotive or base station radio can provide literally a wide spectrum of radio networks, networks that can be added as required on the same unit by incorporating the required software. Such a capability means that the challenges of supporting the various levels of operability defined in **DEMAND**, are more functional and political, then they are technical or financial – an important breakthrough in implementing advanced wireless technologies across the transportation industries.

Cognitive Radio: CR is the forthcoming advancement in the use of SDR. It can be simply defined as SDR with intelligence, i.e. artificial intelligence (AI). CR uses the multi-band, multi-function capability of SDR to dynamically meet the parameters of the users wireless

requirements, including transmission power, geographical boundaries, and permitted users. The potential of CR for railroads is to expand upon the spectrum efficiency, data rates, link performance, and interoperability of SDR [7].

Commercial Services: Very few wireless-based applications for railroads are dependent upon real-time data transfer. Rather, most applications, including the most promising ones for advancing railroad operations, e.g., PTM, require relatively little data at relatively infrequent intervals with no consequences as to the safety of the operations. That demand consideration in concert with the nearly ubiquitous coverage of commercial services, whether satellite or terrestrial, suggests that railroads have the opportunity to quickly and inexpensively from a capital investment standpoint, deploy singular applications with commercial services. Unfortunately, it is not uncommon to hear both railroads and suppliers alike referring to PTC as the first step for advancing many business applications. However, that point is not true as has recently been demonstrated by one, if not two Class Is with their pursuit of PTM using wireless data other than that to be deployed eventually for PTC. This same point of not waiting for PTC can also be made as to pursuing the various levels of operability between railroads, other transport modes, and public safety.

The critical point of this section is that there are technologies, spectrum bands, and wireless platforms available that can be used to advance railroad operations now, with or without the advancement of PTC. Unlike PTC which has a greater cost than value, such advancements can greatly improve the railroads' bottom lines in the near future. However, few railroads individually, and certainly not as an industry, have developed a strategic perspective to make such advancements, as will be addressed in **MOVING FORWARD**. Rather, they have near-totally focused on meeting the PTC mandate.

STRATEGIC PERSPECTIVE

The railroads have an unprecedented opportunity to significantly advance their business practices given advancements in the last decade as to the *core technology infrastructure*, i.e., the combination of intelligence, positioning, & communications technologies. As noted earlier, traditional railroading processes have changed relatively little in nearly a century based upon the continued use of track circuits and voice radio. However, with distributed processing, advanced positioning technologies, and digital wireless technologies, railroads can make a paradigm shift in their operations by developing a strategic operations perspective in sync with a strategic technology perspective, a.k.a. *Strategic Railroading*™[8]. This means performing pragmatic analyses of what the demands for technologies are and then balancing that demand against the supply of those technologies in a cost effective manner, including the likely possibility of making significant changes in primary operating processes.

In performing a strategic analysis of the use of wireless, it is necessary to take a *qualifying* approach instead of a *quantifying* approach as could be used for wired communications. That is, the degree of variation in the unique parameters of wireless, e.g., propagation, capacity, power, bandwidth, and access, prevents performing analyses with any degree of reasonable accuracy compared to wired networks. Therefore, the strategic approach presented below is one of identifying general categories of parameters for supply, demand, and value.

Beginning a strategic analysis requires recognizing several primary points:

- There are a seemingly endless number of combinations of technologies and spectrums that can be possibly used. However, each combination varies as to its throughput and coverage characteristics, as well as the cost to deploy;
- No one combination of technology and spectrum is likely to address all of the major requirements of railroads in the most cost effective fashion; and
- The railroads have a substantial investment in wireless infrastructure, albeit much of it requires further investment to meet the FCC's narrowband mandate.

The net of these three points is that a successful wireless strategy may be one that encompasses several sub-strategies based upon grouping together those demand requirements that have similar combinations of coverage and throughput. Subsequently, each sub-strategy can be explored as to the most cost-effective technology solution keeping in mind the opportunity to cost-effectively utilize current infrastructure. Hence, the following is one strategic approach for wireless deployment for railroads based upon developing a *Strategic Demand* perspective in sync with a *Strategic Supply* perspective.

Demand vs. Supply

As noted in **DEMAND**, there are both **Opportunities** and **Operability** perspectives of demand that need to be considered from a strategic demand versus supply perspective.

Opportunities: As should be expected, not all applications have equal value and nor do they have equal data throughput requirements of the wireless network. To address the two together is a critical consideration in the use of wireless technologies. Fortunately for railroads, as shown in Figure 1, one of the most valuable data requirements for wireless, PTM, is also one with the least data requirements. That is, being able to track each train along the main line as to its speed and position provides for PTM, the ability to increase schedule reliability, and the subsequent opportunity to better manage the key operating resources. Contrarily, the most demanding application for wireless, *moving block*, has substantially little value for some railroads, albeit significant value for others.

Figure 1

		VALUE		
		Low	Medium	High
DATA	Low	Remote Switch	Loco Mgmt Loco Maint Crew Mgmt	PTM Loco Fueling
	Medium	Domestic Security	Yard Mgmt <i>Mobile Node</i> Work Order	PTC Traffic Control <i>Flexible Block</i>
	High	Moving Block- East		Moving Block- West

Operability: While railroad INTERoperability has nearly the exclusive attention of railroads currently due to the PTC mandate, the other levels of operability identified in **DEMAND** offer tremendous value as well. However, they have yet to be given any serious consideration partially due to the lack of strategic perspective of how to deploy technologies in sync with a strategic perspective of operations. One way of addressing the various levels of operability for railroads, including the interaction with public safety and other transportation modes, is to consider the different types of geographical coverage required as well as the generic types of throughputs without regard to specific applications.

For railroads, coverage can be view as to 4 primary categories:

- **Main Line:** the inter-city traffic that includes most of a railroad's terrestrial expanse;
- **Metropolitan:** the major metropolitan areas that include multiple railroad facilities;
- **Facility:** an individual yard / facility;
- **Group:** a number of users that require communications between themselves when they are together and they may be disbursed at some time.

As to the type of throughput, wireless applications fall into 6 categories:

- **Monitor:** the transmission of remote data to a source of intelligence. The data flow is in-bound only;
- **Voice:** a two-way transmission that occurs randomly and may be of relatively long duration;
- **Transaction:** the interactive flow of data that is short in nature, but may occur quite frequently;

- **Data Transfer:** the two-way flow of considerable volumes of data that will occur with some predictability as to location or time of day;
- **Loose Control:** often referred to as *SCADA* in other industries, this two-way flow of data is associated with the remote control of equipment that is perhaps timely, but not critical.
- **Process Control:** the two-way flow of control data that is operationally and safety critical.

Matching the 4 coverage categories against the 6 throughput categories results in 24 different possible combinations of the two, and thereby suggesting a like number of individual technology solutions. However, based upon the two studies referenced in **DEMAND**, there are natural clusters of applications, as shown in Figure 2, that reduce the 24 different possibilities to 6 manageable *wireless corridors*, i.e., the deployment of a wireless network to handle a combination of wireless applications with similar coverage and throughput characteristics.

Figure 2

		COVERAGE			
		Main Line	Metropolitan	Facility	Group
THROUGHPUT	Monitor	MONITOR			
	Voice	MOBILE NETWORK		FACILITY NETWORK	GROUP
	Transaction				
	Data Transfer				
	Loose Control	LOOSE CONTROL			
	Process Control	PROCESS CONTROL			

Monitor: A relatively low speed data rate corridor used primarily for inbound messages that may cover a railroad's total network including yards and main line. Applications that would be considered for this network are tracking high value, high security shipments, tracking and diagnostics of remote and mobile equipment, and status of wayside equipment and infrastructure.

Mobile Network: This network is used for both voice and data transmissions for personnel in the field, whether stationary or mobile. This network could replace the extensive use of commercial cellular by railroads.

Facility Network: This wireless corridor is used for voice and data transmissions in individual facilities, office campuses, or yard operations to replace the use of commercial cellular and possibly wired networks. Additionally, the wireless corridor would handle downloads to/from locomotives in support of PTC, event recorders, an on-board video.

Group: This wireless corridor may be used for voice and data transmissions between personnel and/or equipment. The individual network is only operational when the group, e.g., train consist or work gang, are active.

Loose Control: This wireless corridor is a SCADA platform that requires relatively low throughput, but reliable communications. Applications would include code line and remote equipment / infrastructure control.

Process Control: This is a very reliable, available wireless corridor with significant data throughput requirements. The primary application for railroads would be moving block operations.

The consideration of cross industry operability would likely expand the coverage / throughput categories shown in Figure 2 and identify additional and/or expanded wireless corridors. Once complete, the last step of the demand vs. supply analysis is to build technology strategies for each of the wireless corridors. Simply stated a successful wireless strategy is based upon a divide & conquer approach.

MOVING FORWARD

In general, railroads employ wireless technicians, but they don't employ wireless *technologists*, and the effect has been a loss in efficiency of key resources and investment in capital and maintenance costs for excessive infrastructure, including wireless. Unlike technicians, technologists blend a number of disciplines critical for the cost-effective deployment of technologies, including domain knowledge, operations research, finance, IT, and wireless [9]. Technologists are not Six Sigma warriors that are looking to minimize the cost of current processes. Rather, technologists are process engineers that make the business case to use technologies to advance operations in a cost effective fashion. Simply stated, that means pursuing *revolutionary functionality* via *evolutionary deployment* of technologies where applicable. Examples of this theme that have been suggested in this report include

- Using commercial wireless services to report train position and speed data for use by a PTM platform until the network in the 220 MHz range is implemented;
- Incorporating PTM without replacing CAD;
- Expanding *RailInc's EMIS* (rolling stock repair data base service) to track locomotives / trains for providing ETA's for interchange;
- Expanding *RailInc's EMIS* to track locomotives diagnostics/repairs across the industry to support performance-based maintenance.
- Expanding critical tracking systems that exist in other transport modes, or via shippers, to track chain-of-custody as well as provide tracking of critical shipments for shipment and domestic security purposes;

- Implementing digital trunked radio in the rebuilding of the 160-162 MHz band, but only where truly needed, e.g., major metropolitan environments;
- Performing pragmatic data throughput analyses to determine the real demand across a railroad, across the industry, and in interaction with other transport modes and public safety.
- Developing a strategic information flow architecture for cross industry operability based upon the availability of wireless data networks.
- Viewing the locomotive as a *mobile node* on the railroad's IT architecture (as a manufacturer has fixed nodes), and establish the standards for the on-board computer platform for both PTC and business purposes using object oriented (O/O) architecture.

In the light of just the above examples, it is clear that railroads, both individually and collectively as an industry, have the opportunity to greatly improve their operations, reduce costs, and avoid unnecessary investment in excessive slack resources, including track, crews, locomotives, and wireless infrastructure. It is also clear that such advancements will not occur via the traditional management processes of being driven by middle management. As has been demonstrated by one Class I so far with PTM, the directive has to come from the top and be driven by a pragmatic process that ensures proper participation by all parties.

One approach to developing such a strategy is that which was mentioned earlier as to the use of the Business System Planning process (BSP). BSP is a very structured approach, developed by IBM in the 70's that identifies the generators, users, and modifiers of data associated with the business processes involved, whether they be current or identified by technologists. The resulting outcome of BSP is a well defined information flow architecture, including the identification of singular, unique data banks that serve as data clearing

houses, if you will, and thereby avoid the duplication of data storage. With such an understanding, then wireless corridors, as defined earlier, can be identified with individual wireless strategies involving both spectrum and technologies determined accordingly.

As to the point of spectrum specifically, it is understood that a nationwide PTC spectrum needs analysis is being conducted in conjunction with the Transportation Research Board (TRB). However, this is a relatively simple analysis compared to a much more complex set of issues that should be addressed, including the following:

- What are the true data requirements for PTC, both ACCESS and the system being deployed by the freight railroads? And, do those requirements justify additional spectrum over that already obtained in the 220 MHz band by the railroads?
- What are the business applications that could be added to the on-board PTC platform, thereby expanding its functionality as an extension of a railroad's IT architecture? And, does such expansion justify spectrum in addition to that being used for PTC?
- What are the business applications associated with industry intraoperability and cross industry operability as noted earlier? And subsequently, what are the alternatives for spectrum to be so used, again in line with the wireless corridor approach?

In closing, to perform the strategic wireless analyses requires top level commitment by rail management to provide the resources, i.e., the technologists, whether dedicated employees or contractors, to pursue a pragmatic approach. Additionally, given the influence on safety and efficiency, there is a vested interest by suppliers, passenger operations, regulators, and industry associations as well to participate in such analyses.

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AUTHOR INFORMATION

Ron Lindsey has 37 years in the rail industry both as rail management and as an consultant. As rail management Ron has held the positions of Chief Engineer Communications and Director Advanced Train Control for Class I railroads. In the later position he was the architect for the first overlay PTC system that provided the basis for the PTC pursuits by freight railroads to meet the PTC mandate. With 19 years as an independent consultant, meaning that he represents no suppliers nor accept commissions, he has performed a large number of assignments for the FRA, Class Is, and major suppliers directly aligned with the purpose of this document, including the following:

- Conceived and performed the referenced FRA-sponsored study regarding the use of wireless [3];
- Structured and participated in the referenced Demand Study [2];
- Structured and performed a major BSP regarding the intermodal industry [10];
- Performed a strategic Crew Management Study for a Class I;
- Performed a tactical & strategic AEI Study for a Class I;
- Project leader to evaluate the safety and efficiency of the Egyptian National Railways;
- Performed market studies for suppliers in advanced track / catenary inspection systems, advanced grade crossing equipment, and RF propagation tools;
- 15th year of publishing a quarterly journal, *Full Spectrum*, with subscribers including Class Is, FRA, and major suppliers;
- Published in the *Journal of Transportation*, *IEEE Vehicular Technologies*, *Progressive Railroading*, and currently a Contributing Editor for *Railway Age*;
- Frequent speaker at rail conferences, both domestically and internationally;
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GLOSSARY

AAR	Association of American Railroads: Industry association for the Class I railroads.
ACSES	Advanced Civil Speed Enforcement System used by Amtrak as a overlay PTC approach on their cab signaling operation in the Northeast corridor.
Brakeline	the pressurized air pipe that runs throughout the train to operate the brakes in a fail-safe manner. That is, pressurized air keeps the brakes apart from the wheels, and if that line is broken, then the brakes apply.
BSP	Business System Planning: A strategic process developed by IBM to structure an information flow / data bank architecture.
C A D	Computer Assisted Dispatching: the platform that permits the dispatcher to request routing for trains.
Class I Railroad	The largest railroads in the U.S. that exceed \$250 million in operating revenues adjusted for inflation.
Code Line	the non-vital communication link between CAD and the wayside signaling infrastructure that permits the train dispatcher to make requests of the vital wayside infrastructure to route trains as well as provide indication of wayside signals - a SCADA platform.
Dispatcher	an operations individual that determines the routing of trains. Such decisions are protected from being in error via the use of <i>traffic control</i> systems.
Flexible Block	a near optimal traffic control approach of updating a train's movement authority based upon the amount of traffic involved.
Foreign Locomotive	a locomotive owned by one railroad when used by another.
Intelligent Railroad Systems	a general term applied to systems for railroads that use an array of sensors, computers, and digital communications to improve the safety and/or efficiency of railroad operations.
Intermodal	the movement of freight in containers across multiple transport modes.
Mathematical Planner	a set of mathematical algorithms that is used to optimize the objectives of traffic management selected by a railroad for its operation.
Movement Authority	the permission provided to a train crew to advance the train as to distance, speed, and/or time. In signaled territory, the movement authority is provided as an aspect (a configuration of lights) that indicates permission to proceed and speed restriction. In non-signaled territory, the authority is transmitted by the train dispatcher to the train crew.
Moving Block	the ultimate traffic control approach of continuously updating a train's movement authority.
Narrowbanding	a.k.a. refarming, a FCC Point & Order to split the frequencies in half in a portion of the VHF by 2013. An additional Point & Order was issued in March 2007 to note that the same channels would be split again at some point, but no date was provided.

Non-Signaled Territory	a method of train operation in which the primary authority is generated by a manual process(train sheet) or a computerized conflict checker. The transmission of the authority to the train crew is done by the train dispatcher. There are two types of dark territory. One in which there are no signals (most common). The second type, known as Absolute Manual Block, incorporates signals in the territory, but the signals only provide a secondary level of authority within the primary authority, and their aspects are not provided to the dispatcher.
Object Oriented	a software design approach that establishes a number of functional objects for the application being designed with a standard set of messages between the objects. For PTC an O/O on-board platform would permit the suppliers to choose which objects they which to supply without being required to provide the whole system.
Pole Line	the structure that runs parallel to a railroad's tracks upon which some combination of telephone, power, and code lines are carried.
Positive Train Control	a system that is used to prevent train crew errors. There are 4 core objectives of PTC. 1. prevent train to train accidents, 2. prevent trains from over-speeding, an 3. prevent trains from endangering work gangs. An overlay PTC system is one which does not affect the method of operation, meaning that it is not vital.
Proactive Management	using timely status data of resources to predict possible conflicts and then to have solutions provided to reduce the consequences of those conflicts, if not eliminate them all together.
Railinc's EMIS	Equipment Management Information System is an industry-available data base of parameters and repairs to rolling stock that is maintained by the AAR-owned Railinc entity.
R C L	Remote Control Locomotive: a wireless application that permits an individual on the ground to move a locomotive. This application is used for switching in yards. This should not be confused with pursuit of one-person crews which involves main line operations.
S C A D A	Supervisory Control and Data Acquisition: "a system that is placed on top of a real-time control system to control a process that is external to the SCADA system (i.e. a computer, by itself, is not a SCADA system even though it controls its own power consumption and cooling). This implies that the system is not critical to control the process in real time, as there is a separate or integrated real-time automated control system that can respond quickly enough to compensate for process changes within the time constants of the process. The process can be industrial, infrastructure or facility..." (Source: Wikipedia).
Traffic Management	the management of the traffic control process to meet a railroad's objectives for the movement of trains. This is the true purpose of the train <i>dispatcher</i> .
Traffic Control	the process that generates movement authorities that thereby is the <i>vitality</i> of rail operations. This is not what the dispatcher does directly, but is what s/he often initiates in the traffic management process.
Vitality	From a safety design perspective, vitality means that the device / system will fail safely, i.e., with no increase in risk. From a railroad operation standpoint, vitality refers to the functionality of the hardware and/or software that generates movement authorities that provides for the integrity of train movements.

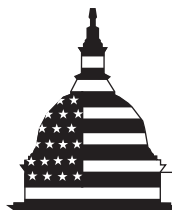
GAO

Report to Congressional Committees

December 2010

RAIL SAFETY

Federal Railroad Administration Should Report on Risks to the Successful Implementation of Mandated Safety Technology



G A O

Accountability * Integrity * Reliability

Why GAO Did This Study

Positive train control (PTC) is a communications-based train control system designed to prevent some serious train accidents. Federal law requires passenger and major freight railroads to install PTC on most major routes by the end of 2015. Railroads must address other risks by implementing other technologies. The Department of Transportation's (DOT) Federal Railroad Administration (FRA) oversees implementation of these technologies and must report to Congress in 2012 on progress in implementing PTC. As requested, this report discusses railroads' progress in developing PTC and the remaining steps to implement it, the benefits of and challenges in implementing other safety technologies, and the extent of FRA's efforts to fulfill the PTC mandate and encourage the implementation of other technologies. To conduct this work, GAO analyzed documents and interviewed FRA and rail industry officials. GAO also interviewed and surveyed rail experts.

What GAO Recommends

GAO recommends that the Secretary of Transportation direct DOT's Administrator of FRA to (1) include in its 2012 report to Congress information about PTC implementation risks and strategies to mitigate them and (2) monitor and report on the adoption of other technologies supported by the agency's efforts. DOT reviewed a draft of this report, provided technical comments, and said it would consider the recommendations.

View [GAO-11-133](#) or key components. For more information, contact Susan Fleming at (202) 512-2834 or flemings@gao.gov.

RAIL SAFETY

Federal Railroad Administration Should Report on Risks to the Successful Implementation of Mandated Safety Technology

What GAO Found

The four largest freight railroads and Amtrak have made progress in developing PTC and are preparing for implementation, but there is a potential for delays in completing the remaining sequence of steps to implement PTC in time for the 2015 deadline. For example, although railroads have worked with suppliers to develop some PTC components, the software needed to test and operate these components remains under development. As a result, it is uncertain whether components will be available when needed, which could create subsequent delays in testing and installing PTC equipment. Additionally, publicly funded commuter railroads may have difficulty in covering the \$2 billion that PTC is estimated to cost them, which could create delays if funding for PTC is not available or require that railroads divert funding from other critical areas, such as maintenance. The uncertainties regarding when the remaining steps to implement PTC can be completed, as well as the related costs, raise the risk that railroads will not meet the implementation deadline, delaying the safety benefits of PTC. Additionally, other critical needs may go unmet if funding is diverted to pay for PTC.

Other technologies hold promise for preventing or mitigating accidents that PTC would not address, but face implementation challenges. Experts identified technologies to improve track inspection, locomotives and other rail vehicles, and switches as having promise to provide additional safety. But challenges to implementing these technologies include their costs, uncertainty about their effectiveness, regulations that could create disincentives to using certain technologies, and lack of interoperability with existing systems and equipment. For example, electronically controlled pneumatic brakes are a promising technology to improve safety by slowing or stopping trains faster, but are expensive and not compatible with some common train operations.

FRA has taken actions to fulfill the PTC mandate and has the opportunity to provide useful information on risks and mitigation strategies to Congress in its 2012 report. FRA has developed PTC regulations, hired new staff to monitor implementation of PTC, and created a grant program to provide funding to railroads. Going forward, as it monitors railroads' progress, FRA will have additional information for determining whether the risks previously discussed are significant enough to jeopardize successful implementation of PTC by the 2015 deadline. Prior GAO reports have noted that the identification of risks and strategies to mitigate them can help ensure the success of major projects. Including such information in FRA's 2012 report would help Congress determine whether additional actions are needed to ensure PTC is implemented successfully. Additionally, FRA's actions to encourage the implementation of other rail safety technologies align with some, but not all, best practices for such efforts. For example, FRA has followed the best practice of involving the industry early in developing new technologies, but it does not monitor the industry's use of technologies that it helped develop. Monitoring and reporting on the industry's adoption of new technologies could help the agency better demonstrate the results of its efforts.

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Abbreviations

AAR	Association of American Railroads
DOT	Department of Transportation
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
PTC	positive train control
R&D	research and development
TTCI	Transportation Technology Center, Inc.

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United States Government Accountability Office
Washington, DC 20548

December 15, 2010

The Honorable John D. Rockefeller
 Chairman
 The Honorable Kay Bailey Hutchison
 Ranking Member
 Committee on Commerce, Science, and Transportation
 United States Senate

The Honorable Frank R. Lautenberg
 Chairman
 The Honorable John Thune
 Ranking Member
 Subcommittee on Surface Transportation and
 Merchant Marine Infrastructure, Safety, and Security
 Committee on Commerce, Science, and Transportation
 United States Senate

Railroad accidents, which are mainly caused by human factors, track defects, or equipment problems, pose safety risks to railroads and their employees, passengers, and the public.¹ Although railroad accidents have generally decreased since 2000, several accidents since 2005 have raised concerns about the potential for the most severe accidents to result in significant casualties. Specifically, in January 2005, a freight train carrying hazardous materials collided with a standing freight train in Graniteville, South Carolina, resulting in the release of a toxic airborne chemical that led to 9 deaths, 292 injuries, and the evacuation of 5,400 people. Then in September 2008, a commuter train collided with a freight train in Los Angeles, California, resulting in 25 deaths and 126 injuries. Both of these accidents were caused by human factors.²

¹Human factor accidents result from unsafe acts of individuals, such as employee errors, and can occur for a number of reasons, such as employee fatigue or inadequate supervision, training, or staffing. Management decisions at the organizational level, such as decisions regarding the allocation of resources or crew scheduling, can have consequences in the workplace that can contribute to human factor accidents.

²Specifically, the accident in South Carolina was caused by a switch left in the wrong position, and the accident in California was caused by a train operator who should have stopped at a signal but instead went through it.

In the wake of these accidents, the Rail Safety Improvement Act of 2008 required passenger and major freight railroads to implement positive train control (PTC) on most major lines by the end of 2015.³ PTC is a system designed to prevent accidents caused by human factors, including train-to-train collisions and derailments that result from trains exceeding safe speeds. It is also designed to prevent incursions into work zones and movement of trains through switches left in the wrong position. PTC accomplishes this by establishing a communications-based network linking trains to equipment along the track and centralized office locations to provide information to a locomotive about its authority to proceed along the track at a particular speed. If the train is going too fast or is approaching a section of track that it should not enter—such as a section of track occupied by another train or work crew—the locomotive computer applies the brakes to slow or stop the train to prevent a derailment due to speeding or a possible collision.⁴ The Department of Transportation (DOT) has noted that the technology has the potential to prevent the most catastrophic types of railroad accidents that result in significant loss of life and property, including the accidents we have previously discussed. The statute also calls for railroads to develop risk-based safety strategies that include a plan for implementing other rail safety technologies and requires railroads to implement certain technologies in areas that both lack train signaling systems and are not required to have PTC installed.

DOT's Federal Railroad Administration (FRA) provides regulatory oversight of the safety of U.S. railroads and is responsible for implementing requirements of the Rail Safety Improvement Act of 2008.⁵ FRA's research and development (R&D) program contributes to the agency's safety oversight by sponsoring and conducting research in collaboration with industry and universities, including the development of new rail safety technologies, and the agency's safety oversight includes

³Pub. L. No. 110-432, div. A, title I, §104(a), 122 stat. 4848, 4856-4858 (Oct. 16, 2008).

⁴Train control systems similar to PTC have been implemented in other countries. In Japan, for example, systems have been implemented to automatically stop or slow trains to prevent collisions, such as when a train operator fails to stop as instructed by a signal. European countries also have train control systems and are currently involved in a joint project to establish interoperability among these systems.

⁵The Rail Safety Improvement Act of 2008 vests certain responsibilities with the Secretary of Transportation, who has since delegated authority to FRA to carry out the functions and exercise the authority vested in the Secretary by the statute. See 49 C.F.R. § 1.49(o), 74 Fed. Reg. 26981 (June 5, 2009), and 49 U.S.C. § 103(g).

efforts to promote the implementation of these technologies. In addition to its safety oversight role, legislation enacted in recent years has significantly expanded FRA's role in the investment and oversight of the development of intercity passenger rail, including high-speed passenger rail.

Emphasizing the need to further improve the safety of the nation's railroad system, as called for in the Rail Safety Improvement Act of 2008, you asked us to examine new rail safety technologies under development and what additional federal roles should be considered to encourage their implementation. This report discusses (1) the progress railroads have made in developing and implementing PTC and the remaining steps to implement PTC systems, (2) the potential benefits of other rail safety technologies under development as well as the challenges to implementing them, and (3) the extent of FRA's efforts to fulfill the PTC mandate and encourage the implementation of other rail safety technologies.

To describe railroads' progress in developing and implementing PTC, as well as the remaining steps to implement PTC systems, we reviewed documents and interviewed officials from the four largest freight railroads, Amtrak, a selection of commuter railroads of different ridership levels and geographic locations, a selection of railroad supply companies that are major PTC suppliers or were recommended by others we interviewed, and associations that represent railroads and suppliers about their progress in developing and implementing PTC. To describe the potential benefits of other rail safety technologies under development, as well as the challenges to implementing them, we sought information from rail safety technology experts and other rail industry stakeholders about their views of various technologies currently under development. Specifically, based on our initial research and interviews, we compiled a list of other rail safety technologies currently under development in the United States. We refined this list on the basis of input from DOT; the Association of American Railroads (AAR); and the Transportation Technology Center, Inc. (TTCI), an industry-operated, DOT-owned railroad research facility.⁶ With

⁶We limited the scope of these technologies to those that would prevent or mitigate train-to-train collisions and derailments. We also did not review other FRA R&D efforts related to accident prevention, such as other research efforts to examine and address causes of accidents related to human factors. For example, FRA has worked with railroads to pilot a system that would allow railroad employees to confidentially report incidents that could have resulted in an accident, which would provide information FRA, railroads, and other stakeholders could use in analyzing and addressing the root causes of such incidents to improve safety.

assistance from the National Academies' Transportation Research Board, we identified a group of 20 rail safety technology experts that we interviewed and then asked to complete a questionnaire about the potential benefits of and challenges to implementing a number of rail safety technologies under development.⁷ We analyzed the results of the questionnaire to identify which technologies are the most promising on the basis of the experts' views of these technologies' potential safety benefits, their worth compared with the cost of additional R&D and implementation, and their stage in product development. We also interviewed officials from railroads, railroad associations, FRA, and the DOT Volpe National Transportation Systems Center (Volpe Center) about the potential benefits and challenges of implementing other rail safety technologies under development. To identify whether there were any major differences with rail safety technologies under development in other countries, we interviewed foreign representatives from railroad industry associations, universities, and governments about the implementation of rail safety technologies in European and Asian countries. To evaluate the extent of FRA's efforts to fulfill the PTC mandate and encourage the implementation of other rail safety technologies, we obtained and reviewed documents from and interviewed FRA officials responsible for the agency's rail safety technology R&D, safety regulatory efforts, and efforts to fulfill the PTC mandate. We also interviewed rail experts and the other stakeholders that we have previously mentioned about their views of FRA's efforts to fulfill the PTC mandate and encourage the implementation of other technologies. See appendix I for a more detailed description of our scope and methodology.

We conducted this performance audit from December 2009 to December 2010 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

The U.S. railroad industry consists mostly of freight railroads but also serves passengers. Freight railroads are divided into classes that are based on revenue. Class I freight railroads earn the most revenue and generally

⁷Of the 20 experts to whom we sent a questionnaire, 19 completed the document.

provide long-haul freight service, while the smaller freight railroads—those in Classes II and III—earn less revenue and generally haul freight shorter distances.⁸ Amtrak provides intercity passenger rail service, while commuter railroads serve passengers traveling within large metropolitan areas. Freight railroads own most of the track in the United States, with a notable exception being the Northeast Corridor between Washington, D.C., and Boston, Massachusetts, which Amtrak predominantly owns.⁹ Railroads grant usage rights to one another, and passenger trains share track with freight railroads. While freight and passenger railroads share many characteristics, there are also key differences in their composition and scope (see table 1).

Table 1: Characteristics of U.S. Freight and Passenger Railroads

Characteristic	Freight railroads	Passenger railroads
Composition	There are 7 Class I freight railroads, of which 4—BNSF Railway, CSX Corporation, Union Pacific, and Norfolk Southern—earn the majority of revenue. There are over 500 Class II and Class III freight railroads, which provide service to connect rural, agricultural, industrial, and port areas to the national freight network.	Amtrak is the only national provider of intercity passenger rail service; there are 25 commuter railroads in the United States.
Scope	The freight industry consists of about 140,000 track miles. U.S. freight traffic in 2007 totaled 2.3 billion tons.	Amtrak operates on 21,000 miles of track, the majority of which is owned by freight railroads. In 2009, Amtrak carried 27.1 million passengers. Commuter railroads, which generally operate on freight- or Amtrak-owned track, provided service to over 450 million passengers in 2009 (as measured in passenger trips).

Source: GAO analysis of industry data.

Note: Figures cited in this table represent the latest available data.

The railroad industry also includes companies that produce railroad supplies, including locomotives, train cars, track, signal equipment, and related components, and national associations that work with and represent railroads. AAR, which primarily represents freight railroads (including all seven Class I freight railroads), as well as Amtrak and some other railroads, develops standards for the implementation of technology, manages the implementation of industrywide technological programs, and

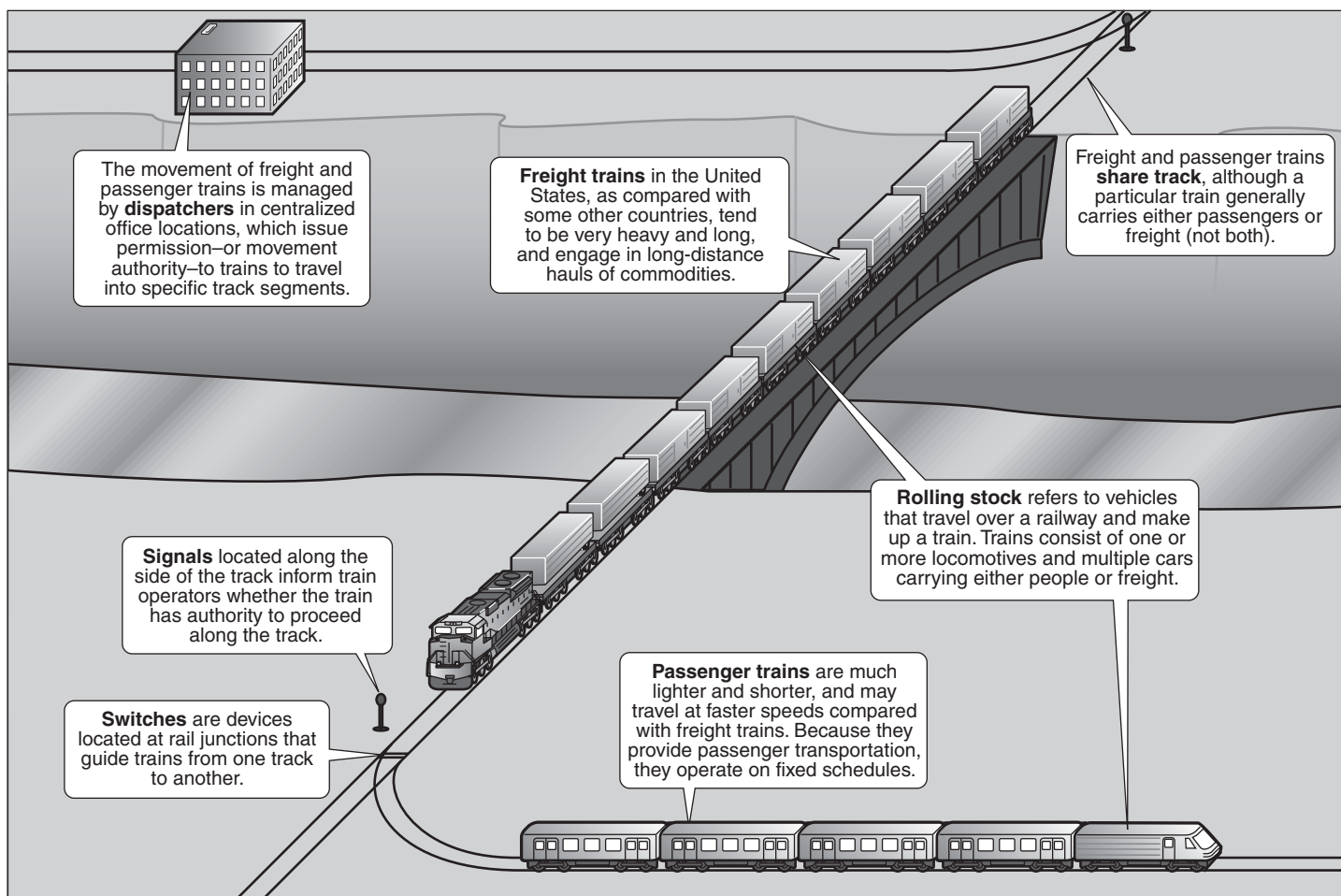
⁸As of 2008, Class I freight railroads are those railroads that earn more than about \$401 million annually; Class II railroads earn from about \$32 million to about \$401 million; and Class III railroads earn less than about \$32 million. Revenue amounts that define railroad classes change each year on the basis of inflation.

⁹Amtrak also owns a section of track in Michigan and some commuter railroads own track.

assesses the railroads' needs for safety and technological development. It also works to develop new technologies at TTCI near Pueblo, Colorado, an FRA-owned railroad research facility operated by AAR through a contract. The American Short Line and Regional Railroad Association represents Class II and Class III freight railroads in legislative and regulatory matters. The American Public Transportation Association represents commuter railroads and develops standards for their use of technology.

The U.S. railroad environment consists of train vehicles (rolling stock) and infrastructure, such as track, bridges and tunnels, switches and signals, and centralized offices with dispatchers (see fig. 1).

Figure 1: Key Components of the U.S. Railroad Environment

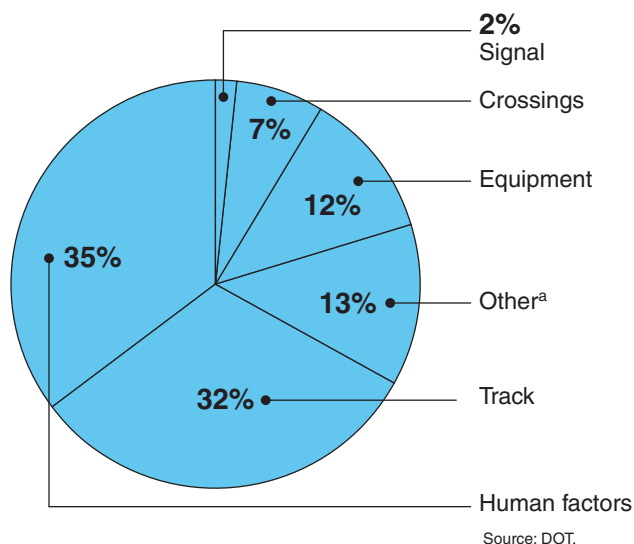
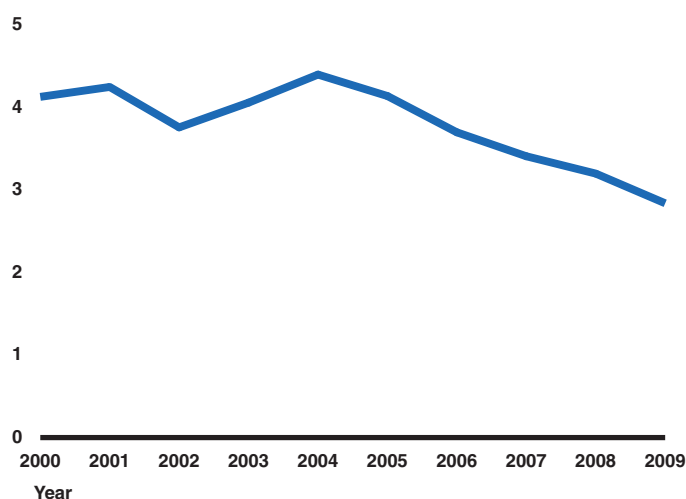


Source: GAO.

Railroad accident rates have generally declined from 2000 to 2009. During that time, human factors and problems with track were the leading causes of rail accidents, according to our analysis of FRA data (see fig. 2).¹⁰ These problems can lead to train derailments or collisions, which can result in significant damage and loss of life. For example, the 2005 accident in Graniteville, South Carolina, was attributed to a switch being left in the wrong position, an example of human error, while the 2008 collision between freight and passenger trains in the Chatsworth neighborhood of Los Angeles, California, was the result of a commuter train going through a red signal it should have stopped at, which was likely caused by human error.¹¹ Track-related causes of accidents include irregular track geometry, which occurs when rail is misaligned or too far apart; breaks in the rail or joints that connect rail segments; and damage to railroad bridges, among other causes. Such defects can lead to train derailments.

¹⁰Human factors that cause accidents include failure to properly use equipment, including brakes and signals, and failure to follow the appropriate train speed, among other causes.

¹¹In its accident report, the National Transportation Safety Board said that the probable cause of the accident was that the commuter train operator failed to obey a red signal because he was distracted by wireless text messaging. The report also noted that the lack of a PTC system to stop the train short of the red signal contributed to the accident. See National Transportation Safety Board, *Collision of Metrolink Train 111 with Union Pacific Train LOF65-12, Chatsworth, California, September 12, 2008*, NTSB/RAR-10/01 (Washington, D.C.: Jan. 21, 2010).

Figure 2: Causes and Rate of Rail Accidents, 2000-2009**Causes****Accidents (per 1 million train miles)^b**

^aThe "other" accident category encompasses a number of other causes, including environmental conditions, such as snow or ice; objects on track; an improperly loaded car; and vandalism.

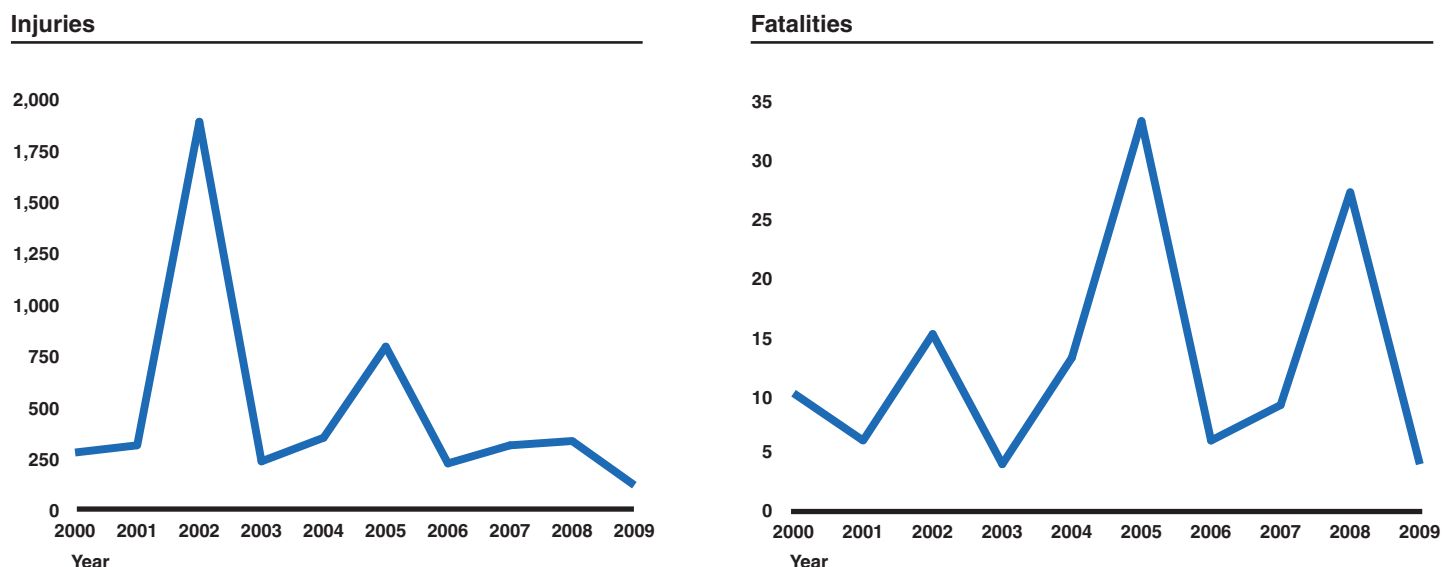
^bThis figure excludes accidents that occurred at intersections between tracks and roads, known as grade crossings.

Although the rate of accidents has decreased from 2000 through 2009, injuries and fatalities have fluctuated, with the largest spikes being tied to specific incidents.¹² For example, injuries increased dramatically in 2002 due to one accident in North Dakota in which 1,441 people were injured from a derailment caused by track problems that resulted in the release of hazardous materials (see fig. 3). The number of fatalities per year from 2000 through 2009 ranged from a low of 4 in 2003 and 2009 to a high of 33 in 2005, the year of the accident in Graniteville, South Carolina, that

¹²The analyses of accidents, injuries, and fatalities exclude accidents that occurred at grade crossings because the causes of such accidents involve issues not related to railroad safety performance, such as driver awareness of grade-crossing safety. Additionally, the rail safety technologies examined in this review primarily address train-to-train collisions and derailments and do not include technologies designed primarily to prevent grade-crossing accidents.

killed 9 people. The second-highest year for fatalities was 2008; that year, there were 27 fatalities, including 25 fatalities from the accident in Los Angeles, California.

Figure 3: Number of Rail-Related Injuries and Fatalities, 2000-2009



Source: DOT.

Note: Figure excludes injuries and fatalities due to trespassing, suicides, and accidents that occurred at grade crossings.

In its role as federal regulator and overseer of railroad safety, FRA prescribes and enforces railroad safety regulations and conducts R&D in support of improved railroad safety and rail transportation policy.¹³ Within the agency, FRA's Office of Railroad Safety promulgates and enforces railroad safety regulations, including requirements for track design and inspection; signal and train control systems; grade-crossing warning device systems; mechanical equipment, such as locomotives and freight

¹³From 2005 to 2008, FRA's oversight was guided by the National Rail Safety Action Plan, which FRA issued in May 2005 to improve its oversight by targeting efforts to high-risk areas. FRA issued a final report on its efforts under this plan in May 2008. As part of our 2007 review of FRA oversight, we said that the National Rail Safety Action Plan provided a reasonable framework for guiding FRA's safety oversight efforts. See GAO, *Rail Safety: The Federal Railroad Administration Is Taking Steps to Better Target Its Oversight, but Assessment of Results Is Needed to Determine Impact*, [GAO-07-149](#) (Washington, D.C.: Jan. 26, 2007).

cars; and railroad operating practices. For example, FRA's regulations for track and equipment include detailed, prescriptive minimum requirements, such as wheel safety requirements and formulas that determine the maximum allowable speeds on curved track. In developing most of its regulations, FRA seeks input from the railroad industry and other organizations through its Railroad Safety Advisory Committee.¹⁴ FRA's Office of Research and Development sponsors and conducts R&D of new rail safety technologies in support of FRA's safety mission. This work contributes information used to support FRA's development of regulations, standards, and best practices as well as encourages the development and use of new safety technologies. FRA's R&D work is done collaboratively with industry and universities and is also supported by the Volpe Center, which is DOT's transportation research center in Cambridge, Massachusetts.

Although its role has traditionally been that of a regulatory agency, recently enacted laws have expanded FRA's role in other areas. The Passenger Rail Investment and Improvement Act of 2008 authorized over \$3.7 billion for three federal programs for high-speed rail, intercity passenger rail congestion, and capital grants,¹⁵ while the American Recovery and Reinvestment Act of 2009 appropriated \$8 billion for these three programs.¹⁶ By creating a significant grant-making role for funding the development of high-speed passenger rail, these laws effectively transformed what was essentially a rail safety organization to one that is making multibillion-dollar investment choices while also carrying out its safety mission. Regarding rail safety technologies, the Rail Safety Improvement Act of 2008 directs FRA to oversee railroads' implementation of PTC and other technologies.¹⁷ Specifically, the act requires passenger and major freight railroads to implement PTC by the

¹⁴To adopt a participatory approach to its rulemaking, in 1996, FRA created the Railroad Safety Advisory Committee, which is designed to bring together all segments of the rail community in developing solutions to safety regulatory issues. The committee includes representatives from railroads, railroad associations, labor, state government groups, and agencies with railroad regulatory safety responsibility in Canada and Mexico.

¹⁵These three programs are Section 301–Capital Assistance for Intercity Passenger Rail Service Grants, Section 302–Congestion Grants, and Section 501–High Speed Rail Corridor Program. See Pub. L. No. 110-432, div. B.

¹⁶Pub. L. No. 111-5, title XII (Feb. 17, 2009).

¹⁷The act also directs FRA to reform its regulations regarding limits on railroad employees' hours of service.

end of 2015, with FRA playing a role as overseer of the industry's implementation through rulemaking and review of railroads' implementation plans.¹⁸ The act also directs FRA to require railroads to improve safety through the development of risk-reduction programs that include plans for implementing new rail safety technologies and to create a grant program to fund the deployment of rail safety technologies, authorized at \$50 million per fiscal year from 2009 through 2013 (see table 2).

Table 2: Rail Safety Technology-Related Requirements of the Rail Safety Improvement Act of 2008

PTC	Other rail safety technologies
<ul style="list-style-type: none"> Class I railroads, commuter railroads, and Amtrak must install PTC on lines that carry passengers or a certain level of traffic and type of hazardous materials by December 2015.^a Railroads' PTC systems must be interoperable. Specifically, they must be able to communicate with one another and provide for seamless movement between sections of track owned by different railroads. Railroads are required to submit plans to FRA by April 2010 outlining how they will implement PTC and address interoperability. FRA must review and approve/disapprove plans by July 2010. Once installed, railroads may not operate PTC systems until they are certified by FRA. FRA must report to Congress on the status of PTC implementation by December 2012. 	<ul style="list-style-type: none"> FRA required to develop a 5-year strategy for improving rail safety that includes improving research efforts to enhance and promote rail safety and performance and report to Congress annually on the strategy beginning in 2009. By October 2009, FRA required to prescribe standards, guidance, regulations, or orders governing the development, implementation, and use of rail safety technologies in areas of track that lack signals or train control systems. By October 2012, Class I freight railroads, intercity and commuter passenger railroads, and other railroads that FRA identifies on the basis of risk must develop a safety risk-reduction program that includes a technology implementation plan, which should describe the railroad's plan to develop and implement new safety technologies to reduce risks identified in the program.^b
Both PTC and other rail safety technologies	
<ul style="list-style-type: none"> FRA required to create a 5-year grant program to support the deployment of PTC and other rail safety technologies, which is authorized at \$50 million per fiscal year from 2009 through 2013.^c 	

Source: Rail Safety Improvement Act of 2008.

^aFRA's PTC rule provides for a "limited operations" exception, allowing a railroad not to implement and operate a PTC system on a particular track segment. See 49 C.F.R. § 236.1019(c). The requirement to install PTC on lines that carry hazardous materials applies only to those lines that carry at least 5 million gross tons of annual traffic and poisonous-by-inhalation hazardous materials. Additionally, some Class II and Class III freight railroads are required to install PTC on certain track segments. FRA has given these railroads additional time—until 2020—to equip some locomotives. FRA also has the authority to grant these smaller railroads certain exemptions from PTC implementation requirements.

¹⁸See 49 U.S.C. § 20157. Prior to the enactment of the Rail Safety Improvement Act of 2008, FRA already had rules under which railroads could develop and implement PTC systems, although these rules did not require that railroads do so. See 70 Fed. Reg. 11,052 (Mar. 7, 2005).

^bThe law requires that such railroads implement PTC by 2018 if they have not already done so.

^cAlthough the grant program is for rail safety technologies broadly, the law and FRA have given PTC priority for funding.

PTC is a communication-based system designed to prevent some accidents caused by human factors, including train-to-train collisions and derailments caused by exceeding safe speeds. Such a system is also designed to prevent incursions into work zones and movement of trains through switches left in the wrong position.¹⁹ PTC achieves these capabilities via communication with various components, namely locomotive computers, devices along the track (known as wayside units), and dispatch systems in centralized office locations (see fig. 4).²⁰ New data radios are being developed to enable wireless communication between locomotives and wayside units. Centralized offices and locomotives have access to a track database with information about track routes and other data, including speed restrictions, track configuration and topography, and the location of infrastructure such as switches and signals that indicate places where a train's speed may need to be enforced by PTC. Using this information, locomotive computers can continuously calculate a train's safe speed. If the train exceeds that speed, the PTC system should enforce braking as necessary. By preventing trains from entering a segment of track occupied by another train or from moving through an improperly aligned switch, PTC would prevent accidents such as those mentioned above that occurred in Los Angeles, California, and Graniteville, South Carolina.²¹ While the law does not require railroads to implement the same PTC system, it does require that railroads' PTC systems be interoperable, which means that the components of different PTC systems must be able to communicate with one another in a manner to provide for the seamless

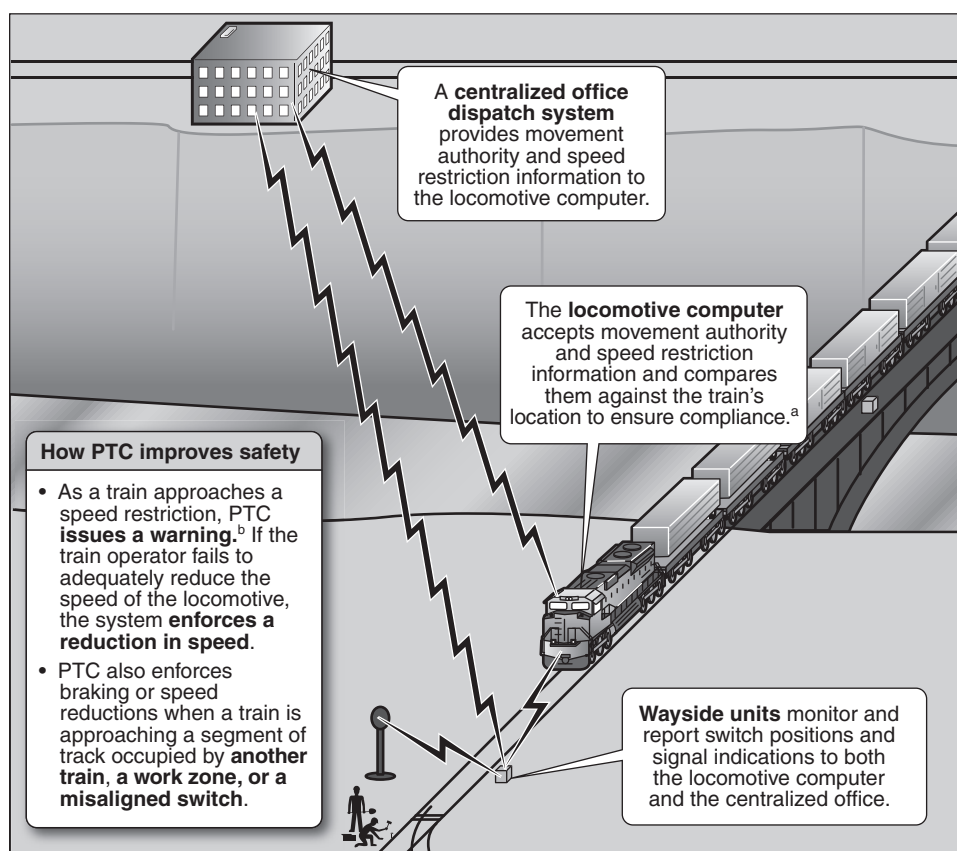
¹⁹ Although railroads are developing and implementing slightly different PTC systems, all systems must be designed to prevent train-to-train collisions, derailments caused by exceeding safe speeds, incursions into work zones, and movement of trains through switches left in the wrong position, as required by the Rail Safety Improvement Act of 2008. See 49 U.S.C. § 20157(i)(3).

²⁰ Wayside units are PTC computers placed along a track at existing switches and signals as well as other locations. Computers in centralized office locations provide route information and issue permission to trains to proceed along track routes.

²¹ When FRA issued its PTC implementation rule in January 2010, the agency provided a regulatory impact analysis of the safety benefits of PTC and estimated that, over a 20-year period, implementing PTC would result in \$440 million to \$674 million in safety benefits from reduced accidents, about one-third of which would result from avoided fatalities. See 75 Fed. Reg. 2598, 2684 (Jan. 15, 2010).

movement of trains as they cross track owned by different railroads that may have implemented different PTC systems.

Figure 4: Basic Operation of PTC



Source: GAO.

^aTrain location information is determined through various methods depending on the specific PTC system, including through satellite-based positioning systems and sensors installed along the track.

^bAlthough the law does not require PTC systems to issue such warnings, the PTC systems that most railroads are implementing will do so.

Train control systems similar to PTC already exist in other countries. For example, a system to automatically stop trains if a train operator fails to stop a train at a stop signal has been widely used in Japan since the 1960s, although this system has been upgraded over time to provide advanced warning of the need to slow a train and automatically apply train brakes in such situations. A more advanced system to continuously calculate a train's safe speed—similar to the capability that PTC is designed to

achieve—is being implemented on the country’s high-speed passenger rail lines. In Europe, countries use various signal and train control systems, presenting technical and logistical challenges for trains that travel between countries. To establish interoperability among these systems, the European Union has embarked on an effort to implement the European Rail Traffic Management System, a common signaling and train control system, as well as a radio communications network, that would overlay countries’ existing signal and train control systems to establish interoperability among them.²² Like PTC, this system relies on a locomotive computer to calculate a train’s safe speed and enforce that speed on the basis of certain information, such as a train’s movement authority, the track speed limit, and the position of signals ahead of the train.

In addition to the implementation plans outlined in the Rail Safety Improvement Act of 2008, FRA’s subsequent PTC regulations also require railroads to submit PTC development plans and PTC safety plans. These three plans are related, and FRA requires different information for each of them:

- *PTC development plan:*²³ To get approval for the type of PTC system a railroad intends to install, the railroad must submit to FRA a plan describing the PTC system the railroad intends to implement and the railroad operations the PTC system will be used with.²⁴ Following FRA’s review of this plan, if approved, the agency would issue the system described in the plan a “type approval,” which is a number assigned to a particular PTC system indicating FRA agreement that the system could fulfill the requirements of the PTC regulations.²⁵

²²The European Rail Traffic Management System is expected to be implemented on over 15,000 miles of track in Europe by 2020.

²³49 C.F.R. §§ 236.1009 and 236.1013.

²⁴If the railroad intends to implement a PTC system that FRA has already approved, a railroad may instead submit documentation of that prior approval. FRA’s PTC regulations also allowed railroads to submit a “notice of product intent” instead of the PTC development plan, which would describe the functions of the proposed PTC system but include fewer details about its operation. However, a railroad that elects to do this could receive only “provisional” approval of its PTC implementation plan, requiring it to submit a PTC development plan or plans to implement a system that has already received a type approval from FRA within 270 days to qualify for full approval.

²⁵49 C.F.R. §§ 236.1013(b) and 236.1003.

-
- *PTC implementation plan:* This plan describes the functional requirements of the proposed PTC system, how the PTC system will achieve interoperability between the host railroad (the railroad that owns the track) and the tenant railroads (those railroads that operate on the host's track), how the PTC system will be installed first on track routes with greater risk, the sequence and schedule for installing PTC on specific track segments, and other information about PTC equipment to be installed on rolling stock and along the track. The law required railroads to submit these plans by April 16, 2010, and FRA to review and approve or disapprove them within 90 days.
 - *PTC safety plan:*²⁶ This plan must include information about planned procedures for testing the system during and after installation, as well as information about safety hazards and risks the system will address, among other requirements. By approving a safety plan, FRA certifies a railroad's PTC system, which must happen before a railroad can operate a PTC system in revenue service. FRA set no specific deadline for railroads to submit this plan.

In its PTC rulemaking, FRA also included requirements for implementing PTC on high-speed passenger rail lines, with trains operating at or above 90 miles per hour, that specify additional safety functions for PTC systems installed for trains operating at these higher speeds.²⁷ FRA's High-Speed Rail Safety Strategy, released in November 2009, acknowledges the importance of implementing PTC for high-speed passenger rail operation and also calls for the evaluation of other specific technologies to determine their suitability for reducing risk for high-speed rail.

²⁶ 49 C.F.R. § 236.1009.

²⁷ For example, a railroad that operates passenger trains above 125 miles per hour must explain in its PTC safety plan how its PTC system is designed to detect incursions onto the track, such as from motor vehicles diverging onto the track from adjacent roads and bridges. See 49 C.F.R. § 236.1007(c).

Railroad Industry Has Made Progress in Developing PTC, but Key Tasks Remain to Completing Implementation

Railroad Industry Has Made Progress in Developing PTC Components, and Railroads Are Preparing for Widespread Implementation

Amtrak and the four largest Class I freight railroads have led PTC development efforts and most other railroads plan to implement PTC systems developed by these railroads.²⁸ Amtrak worked with suppliers to develop PTC for the Northeast Corridor and began installation in 2000.²⁹ Since that time, Amtrak has made improvements to this system, and FRA certified Amtrak's PTC system on the Northeast Corridor in May 2010—the first PTC system FRA certified under the PTC rules it issued in January 2010. Amtrak has also installed a different PTC system on a portion of track in southern Michigan. The four largest Class I freight railroads have identified suppliers of PTC technology and are working with these suppliers to develop PTC components; however, they have not yet installed PTC, except for some limited pilot installations.³⁰ Although there are differences between the PTC systems being installed by Amtrak and those being installed by the freight railroads, they are designed to achieve the same basic functions.

The PTC systems being developed by the four largest Class I freight railroads differ from PTC systems that exist in other countries and on

²⁸One exception is the Alaska Railroad, which began implementing a train control system in 1997 that it is upgrading to achieve PTC certification under the current FRA rules. Additionally, four other commuter railroads and a Class III freight railroad indicated in their PTC implementation plans that they intend to install PTC systems other than those being developed by Amtrak and the four largest Class I freight railroads.

²⁹In 1998, during the time Amtrak was upgrading the Northeast Corridor to permit operation of high-speed passenger trains—a service known today as Acela—FRA required Amtrak to install a new train control system on some portions of the corridor as a safety measure. That system, with some additional communications upgrades, will serve as Amtrak's PTC system on the Northeast Corridor.

³⁰BNSF Railway began development of a PTC system in 2002. Although FRA has not yet certified that this system meets the requirements outlined in the agency's January 2010 PTC rules, FRA had approved this system under prior regulations that had governed development of PTC systems in 2006.

some Amtrak routes. According to AAR officials, existing PTC systems were designed specifically for passenger rail operations and would not address the needs of the U.S. freight railroads. For example, the system that Amtrak uses on the Northeast Corridor combines PTC speed enforcement capabilities with an existing onboard system that provides track status information, such as signal status, to the locomotive engineer. Not all of the freight railroads currently use such an onboard track information system, and such a system would not be feasible to use on segments of track that lack signals, which accounts for about 13,000 miles of track owned by Class I freight railroads that requires PTC. Additionally, in developing new PTC systems, railroads must ensure that their systems are interoperable among the many different railroads that plan to use them.³¹ To achieve interoperability, the four largest Class I freight railroads created the Interoperable Train Control Committee to develop system specifications and standards for interoperability, including protocols for how PTC components should function and communicate with each other as part of an overall system.³² To achieve interoperability with the Class I freight railroads' systems, Amtrak will equip its locomotives that operate on freight-owned track with PTC radios capable of operating on the same frequencies as those used by the freight railroads.

Components of PTC systems being developed by Class I freight railroads are in varying stages of development, with some components currently being produced; however, these components cannot be used or fully tested without software, which remains under development:

- *Wayside units:* These units consist of devices installed at signals, switches, and other locations along the track. The units will monitor the status of signals and switches and communicate that information to

³¹The Rail Safety Improvement Act of 2008 requires that PTC systems provide interoperability, which means that a PTC system can communicate with and control locomotives from different railroads operating trains on the same host railroad's track and that the systems allow trains to move uninterrupted over the boundaries between host railroads. See 49 U.S.C. § 20157(a)(2),(i)(1). Railroads plan to achieve interoperability through the use of common technology and the development and use of standard communication protocols that will allow communication between the locomotives and PTC infrastructure of different railroads.

³²In addition to the four Class I freight railroads that formed this committee, AAR, Amtrak, Kansas City Southern (a Class I freight railroad), the two Canadian-owned Class I freight railroads, some commuter railroads, and FRA also participate.

locomotives directly or through railroads' centralized office systems. Hardware for these units is currently available and being tested by railroads.

- *Locomotive computers:* These computers will provide centralized offices information on the train's location. Based on the status of upcoming signals or switches—which will be communicated to the locomotive by the wayside units—the locomotive computer will calculate the train's braking distance and enforce braking, if needed, to slow or stop a train to comply with speed restrictions and ensure it does not enter a segment of track occupied by another train or a work crew. Locomotive computers are available for railroads to install on newer locomotives. However, railroad associations told us that older locomotives that lack electronic systems will have to be upgraded before such computers and other PTC components can be installed on them.
- *Data radios:* The freight railroads' PTC systems require the use of new data radios installed on locomotives and wayside units to enable PTC communication. Prototype specifications for these radios are still under development, and the railroad industry estimates that these radios will be in production starting in early 2012. The four largest Class I freight railroads share ownership in the company that is developing PTC data radios and jointly purchased radio spectrum to enable PTC communications.

For these components to operate as a system, PTC software is necessary to perform all train control functions, including determining a train's location and calculating a train's braking distance. Complete PTC systems cannot be tested and implemented until software is finalized. PTC software is still under development, and railroad industry officials told us they expect it to be available sometime in 2011.

Forty-one railroads submitted their required PTC implementation plans to FRA in 2010, comprising the 7 Class I freight railroads, 2 Class II freight railroads, 9 Class III freight railroads, Amtrak, and 22 commuter

railroads.³³ In these plans, railroads were required to provide information about the extent to which they will implement PTC, provide a schedule for progressive implementation, and prioritize implementation on the basis of risk.³⁴ Railroads have begun implementing PTC in some locations. Amtrak has installed PTC on just over 200 miles of the 363 miles it owns along the Northeast Corridor and plans to expand its system along the corridor and its connections. It has also installed PTC on about 60 miles of track in southern Michigan and will extend this system along the full 97 miles of track it owns in that area. Class I freight railroads have selected the PTC systems they intend to implement and have informed FRA of their selections by submitting PTC development plans. Some freight railroads and commuter railroads that operate on the Northeast Corridor are already equipped with Amtrak's PTC system. Commuter railroads that connect with the corridor will equip their additional rail lines with this system.

Other freight and commuter railroads that are required to implement PTC have not yet begun implementation. Many of these commuter railroads and Class II and Class III freight railroads plan to implement the same systems being developed by the Class I freight railroads.³⁵ As we have previously stated, components for PTC systems being developed by the Class I freight railroads are not yet available. Officials from the American Public Transportation Association and the American Short Line and Regional Railroad Association—which represent commuter railroads and Class II and Class III freight railroads, respectively—told us that those railroads are awaiting these components to begin installation of PTC. While only a small number of Class II and Class III freight railroads are required by the Rail Safety Improvement Act of 2008 to implement PTC on

³³The Rail Safety Improvement Act of 2008 specifically required all Class I freight railroads, Amtrak, and commuter railroads to submit PTC implementation plans. See 49 U.S.C. § 20157(a). In its PTC rulemaking, FRA clarified that Class II and Class III freight railroads that host passenger rail service must also file PTC implementation plans. See 49 C.F.R. § 236.1005. Other railroads that must install PTC equipment only on their locomotives were not required to submit PTC implementation plans; however, FRA directed railroads submitting PTC implementation plans to identify these other tenant railroads in their plans. This included some commuter railroads that do not own track.

³⁴In reviewing these plans, FRA approved implementation plans from five smaller freight railroads and one commuter railroad that requested exemption from implementing PTC on their track.

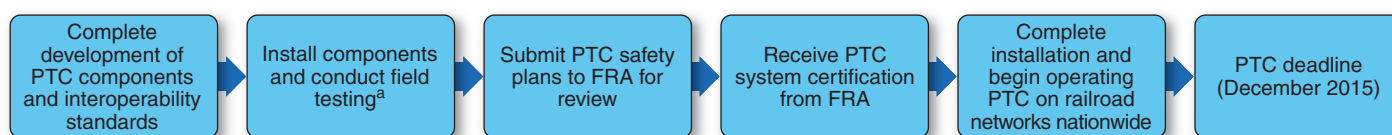
³⁵Amtrak also plans to install the freight railroads' systems on its locomotives that operate on tracks owned by freight or commuter railroads that are implementing those systems. Amtrak will also install the same systems on a few discrete track segments that it owns.

their property, FRA regulations require some additional Class II and Class III freight railroads to install PTC on their locomotives if they operate on track equipped with PTC and share that track with passenger trains.³⁶

Key Steps Remain to Implement PTC by 2015, with a Potential for Delay

By law, the rail industry must complete development, testing, and full implementation of PTC on most major routes within 5 years. Progress has been made by railroads and suppliers in preparing to implement PTC, but many actions must still be taken to achieve full implementation of PTC, and they must be completed in a specific sequence (see fig. 5). Since PTC implementation requires the completion of a specific sequence of steps, any delay in one step could affect the entire implementation schedule, potentially resulting in railroads missing the implementation deadline, which would delay achieving the intended safety benefits of PTC.

Figure 5: Sequence of the Railroad Industry's Upcoming PTC Implementation Steps



Source: GAO.

^aSome installation of components has begun. Also, railroads plan to conduct tests throughout these implementation steps, including tests required by FRA to receive system certification.

As we have previously discussed, all PTC components for the Class I freight railroads' systems are not yet developed. In addition, the development of PTC software and new data radios requires the development of interoperability standards, which the four largest Class I freight railroads and AAR have not yet finalized.³⁷ Specifically, AAR officials told us that the Interoperable Train Control Committee had expected to complete all of these standards by July 2010, but as of August, only 3 of the approximately 40 standards needed were ready. Furthermore, AAR officials told us in September that although the committee continues

³⁶Class II and Class III freight trains that meet these criteria, but make no more than four trips per day in excess of 20 miles, are not required to equip locomotives with PTC until 2020. See 49 C.F.R. § 236.1006.

³⁷Interoperability standards would address a number of technical issues associated with implementing interoperable PTC systems, such as standards for communications and data management.

to make progress in developing these standards and has consolidated some standards to cut down the total needed, it has not set a new date for when it expects to complete this effort. AAR officials explained that delays are due to the complexity and amount of work that must be completed. FRA officials monitoring this effort told us in September that they do not know when the standards will be completed, and that they have some concerns about the potential for the delay in developing these standards to impact railroads' ability to procure PTC components in a timely manner. FRA officials also said that although it is their understanding that the remaining standards have been drafted and are undergoing industry review, they expect this process to last at least through the first quarter of calendar year 2011.

System complexity was a factor that led to delays in an earlier PTC development effort. In 2001, FRA, Amtrak, the Union Pacific Railroad, AAR, and the State of Illinois created the North American Joint Positive Train Control Project, an objective of which was the development of interoperable PTC standards. However, this objective was not achieved by the time the project came to a close in 2006.³⁸ Specifically, system testing revealed that a significant amount of software development would be required for the PTC system to be compatible with normal railroad operations, which FRA concluded would require several additional years to complete.

Railroads currently expect that key PTC components will be available by 2012, but there is uncertainty regarding whether this can be achieved, given the delays in developing the interoperability standards and current lack of software for PTC components. Any delays in component development would consequently delay pilot installations for field testing. The lack of developed components raises questions about the technological maturity of the Class I freights' PTC systems. If the railroad industry is unable to develop fully functional components within the expected time frame, it is possible that testing and installation of these components could not be completed by the 2015 deadline. Our prior work

³⁸While this specific project came to a close in 2006, further development and testing of PTC was moved to TPCI in Pueblo, Colorado. In its project report, FRA stated that lessons learned from the project included the necessity for incremental development of such a complex system, the need for thorough and unambiguous specifications, early test planning, and a rigorous sequence of development steps. See Federal Railroad Administration, *Research Results: The North American Joint Positive Train Control (NAJPTC) Project* (April 2009).

examining the development of military weapon systems has shown that demonstrating a high level of maturity before allowing new technologies into product development programs increases the chance for successful implementation, and that, conversely, technologies that were included in a product development program before they were mature later contributed to cost increases and schedule delays.³⁹

Once PTC components are developed, railroads must test them in the field to ensure that PTC systems function properly and that components of PTC systems are able to communicate with each other regardless of railroad ownership. Any problems that are identified during the field-testing process will need to be addressed to ensure the PTC systems function as required. AAR officials told us that PTC tests have only been conducted in very controlled environments, as opposed to a truly operational environment where the systems could experience stress.⁴⁰ For example, railroads must ensure that PTC systems provide reliable communication among centralized offices, wayside units, and locomotives. However, it is uncertain how well system communication will fare in densely populated areas, such as Chicago, Illinois, where many railroads—both passenger and freight—operate simultaneously.⁴¹ Furthermore, railroad industry officials have expressed concern that all electrical components associated with PTC contain inherent failure rates. Since PTC implementation requires the installation of a large number of devices, the possibility of failure must be addressed and railroads must ensure that any possible failures do not negatively affect railroad safety or operational capacity. Any problems identified during field testing, if they cannot be quickly addressed, could contribute to missing the PTC implementation deadline. Conversely, implementing an immature system to meet the deadline could pose serious safety risks. After railroads complete PTC field tests, they must submit safety plans to FRA for review, and FRA must certify PTC systems before railroads can begin operating them in revenue service.

³⁹GAO, *Joint Strike Fighter: Additional Costs and Delays Risk Not Meeting Warfighter Requirements on Time*, [GAO-10-382](#) (Washington, D.C.: Mar. 19, 2010); and *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*, [GAO/NSIAD-99-162](#) (Washington, D.C.: July 30, 1999).

⁴⁰While BNSF Railway has installed and tested PTC on some subdivisions, the system has not yet been tested with the simultaneous operation of freight trains and Amtrak passenger trains.

⁴¹Officials from the company developing PTC radios told us they are considering St. Louis, Missouri, as a possible testing ground, given the city's similarities in geography and railroad density to Chicago, Illinois.

Given the extent to which railroads must implement PTC, installation will require a considerable amount of work, since it will include the installation of thousands of physical devices on both track and locomotives. Class I freight railroads, for example, must implement PTC on over 70,000 of the approximately 94,000 miles over which they operate, which is about 75 percent of their network.⁴² The railroad industry estimates that about 50,000 wayside units must be installed along track, and data radios must be installed on each wayside unit. Class I freight railroads also expect to install PTC computers and data radios on over 17,000 locomotives, which represent about 70 percent of their fleet that is used for mainline operations. Additionally, commuter railroads must install PTC on their vehicles, even if the railroads do not own track, which FRA estimates will mean equipping about 4,100 vehicles. As we have previously stated, PTC computers are available for installation on new locomotives, but some older locomotives need to be upgraded first before PTC can be installed. Officials at some Class I freight railroads and commuter railroads have expressed concern that a limited number of companies are currently responsible for supplying PTC components to railroads, and that the availability of equipment could impact railroads' ability to complete implementation on time. While rail supply companies told us they expect to meet the demand for PTC components, some also acknowledged that they may need to expand to do so.

Completing implementation will be costly for the railroad industry and could make it difficult for commuter and smaller freight railroads to meet the 2015 deadline. In 2009, FRA estimated that developing, purchasing, installing, and maintaining PTC would likely cost railroads between \$9.5 billion and \$13.1 billion. However, because these costs are still uncertain, the agency acknowledged that costs could be as low as \$6.7 billion or as high as \$22.5 billion. The large amount of equipment needed to complete implementation before the deadline will create a temporary increase in demand for suppliers. FRA has acknowledged that having multiple railroads purchasing the same equipment at the same time could cause the prices of PTC equipment to rise and, therefore, could raise the overall cost of implementation.

⁴²We did not review all railroads' PTC implementation plans to determine the extent to which they must implement PTC. FRA regulations permit exceptions for the implementation of PTC on the basis of certain conditions. For example, FRA may approve exceptions on segments that trains use for limited operations, either at restricted speed or while separated from other trains.

Among passenger railroads, the cost of PTC could be especially problematic. For example, Amtrak officials expressed concern about the cost of PTC implementation on Amtrak routes supported with state funding, since some states may not be able to fund the additional costs associated with PTC implementation.⁴³ Commuter railroads are publicly funded, and some are facing funding shortfalls that are leading them to increase fares or reduce service levels. In their implementation plans, some commuter railroads stated that funding for current operations is already at risk due to stress on their state funding partners, and officials from other commuter railroads told us that they are unsure how they will be able to pay for PTC implementation. The American Public Transportation Association has estimated that PTC implementation will cost the commuter railroad industry at least \$2 billion. Although the cost of implementation will be spread over a number of years, it could still strain the budgets of some commuter railroads.⁴⁴ For example, a transit agency in San Diego, California, told us that implementing PTC for its commuter railroad could cost as much as \$60 million to \$90 million, while the annual capital budget for the agency, which also provides bus service, is about \$10 million. In its PTC implementation plan, this agency stated that it did not have any significant approved funding available for implementation, and that its funding plan assumed receipt of both federal and state funding. Furthermore, the Federal Transit Administration (FTA) has estimated that commuter railroads face a \$12.6 billion backlog to attaining a state of good repair, indicating that these railroads must make significant capital investments to improve the condition of their current assets.⁴⁵ The cost of PTC could further delay commuter railroads making such investments.

⁴³These costs may not be limited to equipping Amtrak locomotives with PTC where they operate on Class I territory. Agreements with freight railroads state that Amtrak pays the incremental costs of using the freight networks. If implementation of PTC along the track is required solely due to the presence of passenger trains, Amtrak may have to cover the cost of implementation.

⁴⁴FRA's cost estimates were for a 20-year period; however, railroads would likely incur all development and installation costs, as well as some maintenance costs, early on. FRA's analysis indicates that about 50 percent of the total cost of PTC implementation would be incurred through 2015.

⁴⁵Federal Transit Administration, *National State of Good Repair Assessment* (June 2010).

Class II and Class III freight railroads may also have difficulty in paying for PTC implementation.⁴⁶ These freight railroads earn much less revenue than Class I freight railroads, and officials from the American Short Line and Regional Railroad Association expressed concern about the ability of these railroads to cover the costs of PTC. Class II and Class III freight railroads tend to have older equipment, for which the costs of PTC installation will be higher since, as we have previously discussed, some older locomotives will require electronic upgrades to enable the installation of PTC components. According to officials at the American Short Line and Regional Railroad Association, the cost of installing PTC on some locomotives could exceed the total value of those locomotives. The four Class II and Class III freight railroads that included a description of implementation risks in their PTC implementation plans included cost as a risk factor, with one railroad noting that paying for PTC will require it to divert funding from its routine maintenance requirements. Even the larger freight railroads acknowledged that paying for PTC could have implications on their budgets. Specifically, officials from Class I freight railroads and AAR have indicated that paying for PTC could result in the diversion of funds from capital investments, such as capacity-improving projects, and could impact their ability to invest in other safety technologies.

The uncertainties that we discuss regarding when the remaining tasks to implement PTC can be completed, as well as the cost of doing so, raise certain risks to the successful completion of PTC by the deadline. Potential delays in developing PTC components, software, and interoperability standards, as well as delays that could occur during the subsequent testing and implementation of PTC systems, raise the risk that railroads will not meet the implementation deadline and that the safety benefits of PTC will be delayed. Furthermore, the extent to which commuter railroads and small freight railroads have difficulty in covering the costs of PTC implementation raises the risk that these railroads could miss the deadline if funding is not available or that other critical needs may go unmet if money is diverted to pay for PTC. As we noted, commuter railroads are already facing challenges in funding current operations, and

⁴⁶The total cost of PTC implementation to Class II and Class III railroads is less clear. Although FRA has indicated that only a limited number of these railroads will be required to implement PTC on the basis of the requirements in the Rail Safety Improvement Act of 2008, Class I freight railroads could require railroads that operate in Class I territory equipped with PTC to install PTC on their locomotives.

paying for PTC could impact the ability of these railroads, as well as smaller freight railroads, to make the necessary investments in maintenance.

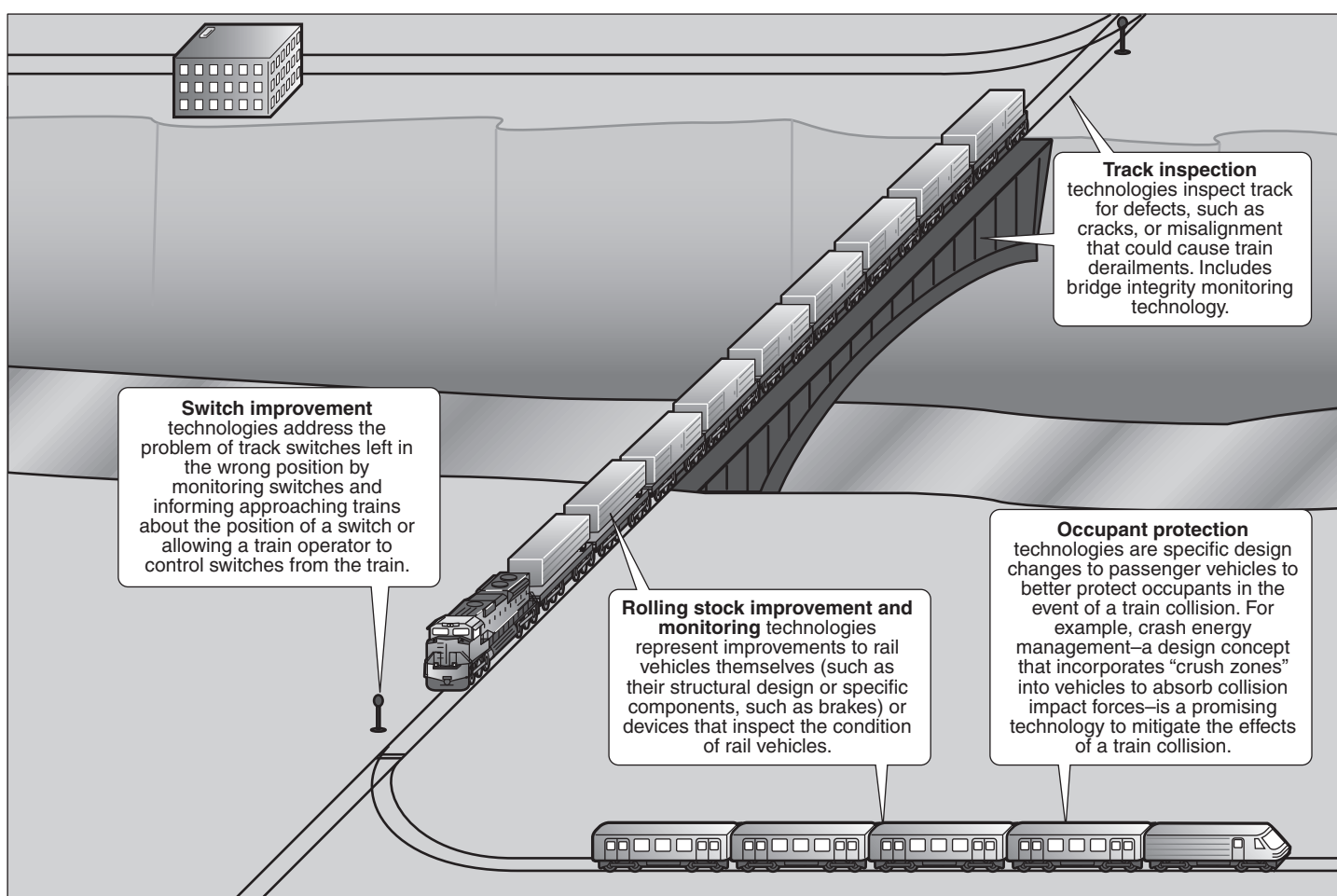
Other Rail Safety Technologies Hold Promise for Preventing or Mitigating Collisions and Derailments, but Face Implementation Challenges

Rail Safety Technologies to Inspect Track, Improve or Monitor Rolling Stock, Protect Occupants, and Improve Switches Hold Promise for Addressing Key Causes of Accidents

While PTC addresses some accidents caused by human factors, other technologies being developed can address other causes of accidents, such as problems with track or equipment that account for a significant portion of accidents and would not be addressed by PTC. According to experts and other stakeholders from the railroad industry and government, a number of rail safety technologies under development hold promise for improving safety.⁴⁷ In particular, some of these technologies may be essential for addressing the safety of high-speed passenger rail or areas of track that lack signals or PTC. We identified four broad categories of technologies that current development efforts are focused in. Figure 6 shows where such technologies can be integrated into the existing rail environment to improve safety.

⁴⁷Information in this section of our report is based, in part, on information we obtained from rail safety technology experts through interviews and a subsequent questionnaire. Of the 20 experts we identified and interviewed, 19 responded to the questionnaire; however, the number of experts that answered each question varied because experts were asked to answer only those questions about technologies that they were familiar with, and not every expert was familiar with all of the technologies in the questionnaire. For detailed results of the questionnaire, see appendix III.

Figure 6: Integration of Other Rail Safety Technologies in the Rail Environment



Source: GAO.

- Track inspection:* New technologies have the potential to better inspect track for cracks in the rail that could lead to breakage as well as measure the track’s alignment to ensure that rails are laid at the proper angle and distance apart. About one-third of rail accidents are caused by track defects, such as broken or misaligned rail that could cause a train to derail. Experts and other stakeholders noted that some of these technologies have the potential to allow railroads to better manage track risks by providing more accurate data about the size and nature of track defects. Railroads could then monitor such defects over time and make risk-based track maintenance decisions. Such technologies could be particularly useful for high-speed passenger rail operations, since track that carries high-speed trains must be maintained to a higher standard.

- *Switch improvement:* These technologies address the problem of track switches left in the wrong position, which could lead a train onto the wrong track and cause an accident. Several experts observed that technology to monitor and indicate the position of a switch would provide particular benefit for sections of track that lack signals, and two experts told us the technology would have prevented the 2005 accident in Graniteville, South Carolina. This technology is among those that the Rail Safety Improvement Act of 2008 suggests DOT include when prescribing the development and implementation of rail safety technologies in areas of track that lack signals or train control systems.
- *Rolling stock improvement and monitoring:* New technologies to improve the function or design of rail vehicles, as well as devices to inspect them, can provide safety benefits by improving the safe operation of trains and better identify when train components develop problems that could cause an accident. For example, experts and other stakeholders noted that technology to provide real-time monitoring of certain wheel assembly components is an important technology for high-speed trains, since overheating of these components can quickly lead to failure. European officials from an association of rail supply companies told us this technology is used for European high-speed passenger trains.⁴⁸
- *Occupant protection:* Incorporating new designs into passenger rail vehicles, such as crash energy management—a design concept that incorporates parts designed to crumple under stress to absorb collision energy to mitigate impact forces—represents a new way of thinking about crashworthiness, which has traditionally involved designing vehicles with hard exteriors to resist deformation. European rail officials told us this technology is used in European passenger trains. FRA’s crashworthiness regulations have included standards for incorporating crash energy management into rail vehicles since 1999 and require crash energy management for high-speed passenger trains operating up to 150 miles per hour.⁴⁹

Among the technologies we examined, we identified some as being more promising, based on experts’ views about the technologies’ potential to improve safety, their worth in doing so compared with their additional

⁴⁸ European safety standards for high-speed passenger trains that travel above 155 miles per hour require the installation of onboard equipment to monitor the temperature of bearings in the cars’ wheel assemblies and inform the driver of any potentially dangerous deterioration.

⁴⁹ 49 C.F.R. § 238.403.

cost for development and implementation, and their being in a later stage of product development (see table 3).⁵⁰

Table 3: Most Promising Rail Safety Technologies under Development, Based on Expert Views, by Category

Technology	Description
Track inspection	
Bridge integrity monitoring systems	Sensor-based systems used to detect bridge damage or structural defects that could lead to collapse.
Rolling stock improvement and monitoring	
Wayside detectors	Devices installed along tracks that inspect vehicles as they pass to monitor vehicle health or examine them to identify potential problems that could cause an accident in certain locations, such as examining wheel structures before trains go down hills.
Electronically controlled pneumatic brakes	Advanced braking system that increases the speed at which brake signals are sent through a train, which can reduce stopping distances and prevent braking-related derailments.
Occupant protection	
Crash energy management	Incorporates crush zones into vehicle design to absorb energy and better control the deformation of a vehicle in the event of a collision to preserve occupant space.
Improved design of interior passenger car fixtures	Modification to interior fixtures of passenger cars, such as seats and tables, to reduce the severity of injury during an accident.
Switch improvement	
Switch position monitors/indicators	Monitors the position of track switches and provides this information to train operators.

Source: GAO analysis of expert questionnaire responses.

⁵⁰Specifically, experts viewed certain technologies as having more potential to improve safety, being worth the additional cost of R&D and implementation, and being in later stages of product development. In our questionnaire, we asked experts their views on technology maturity using five categories of technology development ordered from earlier to later stages: concept exploration, proof of concept and initial design, refinement and pilot testing, production and some deployment, and widespread industry deployment. Because we focused on technologies currently under development, we removed from our scope any technologies for which there was a consensus among the experts that they were fully deployed.

Regarding their stage in product development and implementation, experts mostly viewed these technologies as having some deployment, except for wayside detectors, which experts viewed as more widely deployed; however, this may vary depending on the type of detector.⁵¹

Some of these most promising technologies are also deployed in other countries; however, differences in the nature of rail systems in those countries as compared with the United States could mean that the benefits of a particular technology may not be the same. As we have previously discussed, the U.S. rail system consists mostly of freight railroads; however, in Europe and Japan, passenger rail, including high-speed rail, is more predominant. Such differences in the rail systems may lead to differences in how new rail safety technologies are implemented. For example, although foreign stakeholders told us that electronically controlled pneumatic brakes are common on passenger trains in Europe, they are not used on freight trains. Because European freight trains are generally lighter and shorter than American freight trains, they can stop in a shorter time and distance than longer, heavier American freight trains can stop. Consequently, a European freight railroad would realize less benefit from the improved stopping efficiency that this technology offers. Additionally, unlike in the United States, there is not a significant amount of European track miles that lack signals, so the challenge of addressing safety for unsignaled areas with technologies such as switch position monitors/indicators is generally not an issue. Additionally, philosophical differences in approaches to railroad safety may affect how rail safety technologies are implemented. Specifically, foreign rail officials and academics with knowledge of rail practices in Europe and Japan, as well as FRA officials, told us that safety efforts in Europe and Japan are driven more by a desire to avoid accidents, rather than to mitigate their effects.

⁵¹For example, one academic expert noted that infrared-based devices that examine wheel bearings are mature and deployed, but that newer acoustic-based devices that inspect bearings are being developed and tested.

Cost, Uncertainty about Effectiveness, Regulations, and Lack of Interoperability Create Challenges to Implementing New Rail Safety Technologies

Experts and other stakeholders identified costs, uncertainty about effectiveness, regulations, and lack of interoperability with existing systems and equipment as key challenges to implementing new rail safety technologies:

- *Cost:* Most experts indicated that cost was a major challenge for implementing rail safety technologies in all four technology categories, including for some of the most promising technologies—specifically electronically controlled pneumatic brakes, crash energy management, and switch position monitors/indicators.⁵² Additionally, according to some experts, other stakeholders, and FRA officials, because of the costs they are incurring to implement PTC, railroads are not looking to spend capital to implement other rail safety technologies. Commuter railroads and short line railroads also lack the capital budgets to invest in new technologies. Some experts and other stakeholders, as well as FRA officials, also told us there is sometimes a disconnect between who would pay for a particular technology and who would benefit from it. For example, one of the experts and representatives from a railroad association we interviewed told us that electronically controlled pneumatic brakes would most benefit the railroads, while the cost of installing them would fall on the car owner, which could be a shipping company and not a railroad.
- *Uncertainty about a technology's effectiveness:* Several of the experts and other stakeholders we interviewed identified uncertainty about a technology's effectiveness as a key implementation challenge and noted that proving the effectiveness of a new technology is critical to gaining its acceptance for use by the industry. In particular, most experts noted that uncertainty about effectiveness was a challenge to implementing several of the track inspection and measurement technologies, presumably because of their lack of maturity, since the experts also tended to indicate that these technologies were in the early stages of development.⁵³ The reluctance by railroads to implement a technology due to cost is also

⁵²Specifically, the numbers of experts that identified cost as a major challenge for implementing these technologies were 10 of 12 experts for electronically controlled pneumatic brakes, 7 of 9 experts for crash energy management, and 7 of 11 experts for switch position monitors/indicators. Although a total of 19 experts responded to our questionnaire, the number of experts that answered these questions varied because the experts were only asked to answer questions about technologies they were familiar with.

⁵³For example, 9 of 13 experts said that uncertainty about technology effectiveness was a major challenge for implementing a new track inspection technology that uses lasers to enhance ultrasonic rail inspection (laser-based, noncontact ultrasonic rail inspection), and 8 of 11 experts viewed this technology as being in a pilot testing or proof of concept phase of product development.

affected by uncertainty about a technology's effectiveness. According to FRA officials, railroads will not adopt a new technology unless they know it will deliver a positive return on their investment.

- *Regulations:* Experts and other stakeholders reported a disincentive under current regulations to use new track inspection technologies. Specifically, they were concerned that such technologies identify track defects perceived as too insignificant to pose a safety risk, but which nonetheless require remedial action under current regulations once such defects are identified. Regulations were generally not cited by experts and other stakeholders as a major challenge to implementing the other new technologies.⁵⁴
- *Lack of interoperability with existing systems and equipment:* Most experts indicated in our questionnaire that lack of interoperability was a major implementation challenge for electronically controlled pneumatic brakes.⁵⁵ Specifically, they told us that for such brakes to function properly, all cars on a train would have to be equipped with them, which, although practical for a passenger train or a train that does not exchange cars with another train—such as a train that carries one type of cargo, like coal—would not be practical for a mixed-freight train whose cars are exchanged with other trains, which is common in rail operations. Additionally, some stakeholders said that crash energy management is difficult to retrofit into existing rolling stock. Experts did not agree that lack of interoperability was a major challenge for the other technologies.

⁵⁴FRA regulations provide that if a track owner learns of a rail defect through inspection or other means, operation over the track is not permitted until the rail is replaced or a prescribed remedial action is taken. Such actions include applying joint bars to the track and limiting train speed over the defective track. See 49 C.F.R. § 213.113.

⁵⁵Specifically, 11 of the 12 experts that answered this question indicated that lack of interoperability was a major implementation challenge, while 1 expert said it was a minor challenge.

FRA Has Taken Actions to Fulfill the PTC Mandate and Promote Other Technologies, but Opportunities Exist to Inform Congress of Risks and Improve Monitoring

To Date, FRA Is Taking the Necessary Steps to Fulfill the PTC Mandate

To fulfill the PTC mandate, FRA (1) has developed regulations regarding the implementation of PTC systems, (2) is monitoring PTC implementation efforts, and (3) is managing funding programs to support PTC implementation.

Development of Regulations

In January 2010, FRA issued final regulations on PTC implementation on the basis of requirements in the Rail Safety Improvement Act of 2008.⁵⁶ These regulations were developed in collaboration with the railroad industry and other stakeholders through FRA's Railroad Safety Advisory Committee. Among other things, the regulations describe the requirements of a PTC system; require railroads to submit PTC development, implementation, and safety plans and FRA to review and approve them; require railroads to implement PTC by December 31, 2015; and establish a schedule of civil penalties for violations.

Oversight of Railroads' PTC Implementation Efforts

To oversee railroads' progress in implementing PTC, FRA has provided guidance and is monitoring implementation, including by reviewing railroads' PTC-related plans and directly observing railroads' PTC-related activities. Specifically, FRA has provided guidance to the railroad industry on PTC implementation by speaking at industry conferences, meeting with railroads to discuss PTC implementation plans, and providing railroads

⁵⁶75 Fed. Reg. 2598 (Jan. 15, 2010).

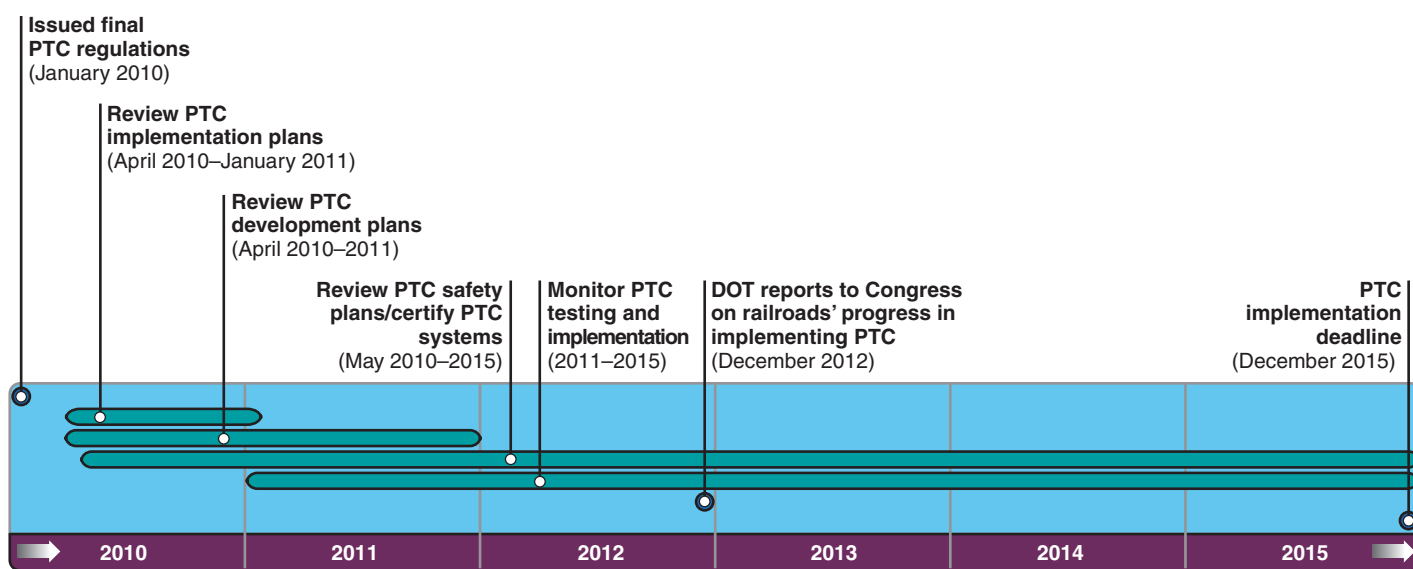
with a template for drafting their PTC implementation plans.⁵⁷ The Rail Safety Improvement Act of 2008 and FRA's regulations require the agency to provide timely review and approval of PTC development, implementation, and safety plans.⁵⁸ FRA must review and approve PTC development plans before railroads can submit their PTC safety plans, receive PTC system certification from FRA, and begin operating PTC systems (see fig. 7). FRA reviewed PTC implementation plans before completing its review of all PTC development plans, since the implementation plans had a review deadline set by statute, whereas development plans did not. As of July 2010, FRA completed its first review of all 41 of the PTC implementation plans railroads submitted. As of December 3, 2010, according to FRA officials, 21 plans were fully approved and 13 were provisionally approved. The remaining 7 plans were disapproved; the agency returned these plans to railroads with requests to make technical corrections or provide more detailed information and resubmit them to FRA for subsequent approval.⁵⁹

⁵⁷FRA is also developing a tool for evaluating risks associated with removing PTC from routes when making decisions regarding rerouting of airborne toxic chemicals. In October 2010, FRA officials told us that the agency would begin a rulemaking to solicit stakeholder comments in developing this tool.

⁵⁸Specifically, the Rail Safety Improvement Act of 2008 requires FRA to review PTC implementation plans within 90 days of receipt. See 49 U.S.C. § 20157(c). Additionally, FRA's final PTC rule calls on the agency to review PTC development plans within 60 days of receipt and PTC safety plans within 180 days of receipt. If FRA is unable to meet the deadlines for PTC development and safety plan reviews, it must notify the relevant railroads. See 49 C.F.R. § 236.1009(j).

⁵⁹The provisional approval FRA issued to some railroads required those railroads to submit a revised PTC implementation plan within 270 days accompanied by a PTC development plan, evidence that the railroad intended to implement a PTC system that FRA had already approved, or a PTC safety plan. FRA requested the railroads with a disapproved plan to meet with the agency to discuss resolution of the remaining issues in their plans. FRA officials expect to issue final approval for five of the seven disapproved plans in December 2010 and are working with the other two railroads in hopes of resolving their remaining issues in early 2011.

Figure 7: Approximate Timeline of Key FRA Actions to Meet the PTC Implementation Mandate



Source: GAO.

Note: Dates are approximations based on information provided by FRA.

FRA has since been reviewing PTC development plans. According to the PTC final rule, FRA, to the extent practicable, will approve, approve with conditions, or disapprove these plans within 60 days of receipt.⁶⁰ In March 2010, three of the four largest Class I freight railroads jointly submitted a PTC development plan. In a May 2010 letter to those railroads, FRA stated it would not complete review of the plan within the 60-day time frame specified in the final rule because agency personnel were needed to review the large number of implementation plans FRA received, which had a review deadline set by statute. FRA completed an initial review of the development plan in July 2010 and sent a letter to the railroads asking them to (1) revise the development plan and resubmit it after making some corrections and (2) provide FRA with specific details on the magnitude of the risk the delay in FRA's review and approval of the development plan would have on the timely implementation of PTC. FRA officials told us

⁶⁰If FRA has not approved, approved with conditions, or disapproved the PTC development plan within the 60-day window, the agency must provide a statement of the reasons why the submission has not been acted on and a projected deadline for doing so. See 49 C.F.R. § 236.1009(j)(2)(iii).

they met with representatives from these railroads in August and October 2010 to discuss resolution of FRA's remaining issues and concerns and are working with the railroads on an ongoing basis to do so. Several experts and other stakeholders told us that if development or implementation plan approvals were delayed, railroads' PTC implementation schedules could, in turn, be delayed, possibly resulting in railroads not meeting the PTC implementation deadline. In this specific case, the three Class I freight railroads noted in a July 2010 letter to FRA that a delay in approving their PTC development plan could delay PTC development and implementation time frames. Other railroads could also be affected, since three other Class I freight railroads, three smaller freight railroads, Amtrak, and nine commuter railroads are relying on the approval of this plan, because they are also implementing the same PTC system.

FRA plans to monitor railroads' progress in implementing PTC by requiring railroads to provide periodic information on implementation progress and by directly observing railroads' testing and implementation of PTC. In its final PTC rule, FRA requires that railroads report annually on the percentage of their trains that are PTC-equipped and operating on PTC-equipped track.⁶¹ FRA officials told us that the intent of this reporting is to monitor railroads' implementation of PTC so that railroads gradually implement this technology in the years leading to the 2015 deadline. Members of the newly established PTC branch within FRA's Office of Safety will conduct further monitoring of PTC implementation. According to FRA officials, these 11 new staff members in headquarters and regional offices will monitor railroads' work to verify the accuracy of information in PTC track databases; observe testing conducted by railroads prior to PTC system certification; and, if needed, advise railroads to conduct more tests or different tests to establish that the PTC system complies with FRA regulations.⁶² Additionally, FRA is required to report to Congress in 2012 on the progress railroads have made in implementing PTC.⁶³

Financial Assistance

FRA manages two funding programs to assist with PTC implementation. First, as required by the Rail Safety Improvement Act of 2008, FRA

⁶¹ 49 C.F.R. § 236.1006(b)(2).

⁶² In advertising for PTC branch staff, FRA sought individuals experienced in the design, construction, maintenance, testing, and use of railroad signal and train control systems, in general, and in PTC systems, in particular. According to FRA officials, these positions have been filled with experienced individuals.

⁶³ 49 U.S.C. § 20157(d).

manages a grant program to fund the deployment of rail safety technologies. This program is authorized to offer up to \$50 million in grants to railroads each year for fiscal years 2009 through 2013. Congress did not appropriate funding for this program in fiscal year 2009 and provided \$50 million in fiscal year 2010.⁶⁴ The law stipulates that funding under this program be prioritized for implementation of PTC over other rail safety technologies. In November 2010, FRA awarded grants totaling \$50 million to seven projects for fiscal year 2010, six of which were related to PTC, while the seventh was awarded for implementation of a risk management system. FRA received 41 applications seeking over \$228 million in funding for the fiscal year 2010 grants. This grant program is particularly popular, but its funding as authorized will cover only a small portion of the estimated costs of PTC implementation, which FRA has acknowledged could range from \$6.7 billion to \$22.5 billion. Second, FRA also manages the Railroad Rehabilitation and Improvement Financing Program, which authorizes FRA to provide loans and loan guarantees up to \$35 billion (\$7 billion of which is reserved for non-Class I freight railroads). Funding awarded under this program may be used for several purposes, including implementation of PTC and other rail safety technologies, but can also be used for more general improvements to infrastructure, including track, bridges, and rail yards. FRA staff told us that as of September 2010, no railroads have applied to this loan program for PTC implementation and speculated that the program's requirement to demonstrate creditworthiness may have deterred some railroads from applying. It may also be too soon in the PTC implementation time frame for most railroads to need loans, if they are not yet purchasing PTC equipment. Officials from the American Short Line and Regional Railroad Association told us that using these loans to pay for PTC would help smaller freight railroads meet the implementation mandate.⁶⁵

In addition, FRA officials said that the agency is working with FTA to see whether FTA could provide financial assistance to commuter railroads for PTC implementation. FRA officials said that to provide this financial assistance, FTA would need to seek additional funds in its annual budget

⁶⁴The funds appropriated in fiscal year 2010 are available until expended. See Consolidated Appropriations Act, 2010, Pub. L. No. 111-117, Div. A, Title I, 123 stat. 3034, 3056 (Dec. 16, 2009).

⁶⁵Additionally, FRA officials told us that PTC implementation projects are eligible for possible competitive funding provided by the American Recovery and Reinvestment Act of 2009. Examination of such funding is beyond the scope of this review.

request to Congress. FTA did not request such funds for fiscal year 2011 and is currently developing its budget request for fiscal year 2012.

FRA Has an Opportunity to Identify and Report to Congress on PTC Implementation Risks and Potential Mitigation Actions

As we have previously discussed, there are uncertainties regarding when the remaining tasks to implement PTC can be completed, which raise certain risks to the successful completion of PTC by the 2015 deadline. FRA officials told us they are aware of some of these risks, but they said that it is too early to know whether they are significant enough to jeopardize successful implementation by the 2015 deadline. However, as FRA moves forward with monitoring railroads' implementation of PTC, the agency will have more information regarding the risks previously discussed. In particular, the agency should have a clearer picture of whether it is likely railroads will meet the 2015 implementation deadline and what the associated implications would be. For example, by the time FRA reports to Congress in 2012 on PTC implementation progress, it will be clearer whether the state of PTC component maturity poses a risk to timely implementation, since the railroad industry currently expects components will be available by 2012. Additionally, the cost to implement PTC should be more certain, and therefore it will be clearer whether problems in financing PTC—particularly for commuter and smaller freight railroads—could lead to delays or whether the costs of PTC could result in other operational needs, such as maintenance, going unmet due to the diversion of funds to pay for PTC.

Our past work has shown that the early identification of risks and strategies to mitigate them can help avoid negative outcomes for the implementation of large-scale projects. For example, our 2004 report examining an Amtrak project to improve the Northeast Corridor noted that early identification and assessment of problems would allow for prompt intervention, increasing the likelihood that corrective action could be taken to get the project back on track.⁶⁶ Furthermore, for our work examining the transition from analog to digital television broadcasting, we pointed out how such efforts are particularly crucial when the implementation of a large-scale project relies on private organizations to

⁶⁶GAO, *Intercity Passenger Rail: Amtrak's Management of Northeast Corridor Improvements Demonstrates Need for Applying Best Practices*, [GAO-04-94](#) (Washington, D.C.: Feb. 27, 2004). The need to address risks early, particularly risks associated with a project's cost and schedule, has long been part of our work to assess efforts related to major capital investments. See GAO, *Executive Guide: Leading Practices in Capital Decision-Making*, [GAO/AIMD-99-32](#) (Washington, D.C.: December 1998).

achieve public benefits.⁶⁷ Such is the case with the implementation of PTC, which was mandated for reasons of public safety but is largely the responsibility of railroads to accomplish. FRA's 2012 report to Congress presents the agency with an opportunity to inform Congress of the likelihood that railroads will meet the 2015 implementation deadline, as well as potential implementation risks and strategies to address them. Such information would help Congress determine whether the railroad industry is on track to successfully implement PTC by 2015 or whether there are major risks associated with this effort that require intervention by Congress, FRA, railroads, or other stakeholders. FRA officials told us they have not yet determined what information will go in their report.

FRA Has Taken Some Actions to Encourage the Implementation of Other Technologies, but Does Not Fully Use Best Practices

In keeping with its mission of promoting safety throughout the national railroad system, FRA has taken a number of actions to encourage the use of rail safety technologies other than PTC—such as electronically controlled pneumatic brakes or switch position monitors/indicators—by (1) collaborating with industry on R&D efforts, (2) supporting demonstration and pilot projects, (3) analyzing technology costs related to benefits, and (4) issuing or revising regulations.⁶⁸

Collaboration with Industry on R&D

FRA has worked with members of the railroad industry—through the Railroad Safety Advisory Committee, AAR, and TTCI—to prioritize and select technologies to be included in FRA's R&D program. FRA and AAR collaborate extensively on R&D projects at TTCI, a DOT-owned, AAR-operated research facility. Additionally, FRA's Office of Research and Development may select a railroad partner when beginning a new R&D project. For example, FRA partnered with one of the largest Class I freight railroads to demonstrate a new technology that measures the interaction between rail cars and the track—known as vehicle/track interaction technology. According to a senior FRA official, these devices are now widely deployed, and FRA continues to study ways to model vehicle/track interaction. Each year, FRA also presents information about its completed and ongoing R&D projects to the Transportation Research Board—a body

⁶⁷GAO, *Digital Television Transition: Increased Federal Planning and Risk Management Could Further Facilitate the DTV Transition*, [GAO-08-43](#) (Washington, D.C.: Nov. 19, 2007).

⁶⁸According to FRA officials, a demonstration project involves testing a technology to show how it works and whether it achieves its intended result. A pilot project generally follows a demonstration project and is used to compile data about the technology to demonstrate its benefits.

that includes railroad industry representatives—which then conducts an evaluation of FRA’s R&D program.⁶⁹ Additionally, the Rail Safety Improvement Act of 2008 called for FRA to develop a railroad safety strategy, which the agency issued in 2010 with its fiscal year 2011 budget request. Although this plan does not include any efforts to encourage implementation of specific rail safety technologies, it does state that FRA’s Office of Research and Development has expanded its use of grants and partnerships with railroads and suppliers to improve stakeholder participation in its R&D and support the demonstration of results as soon as possible.

Support of Demonstration and Pilot Projects

FRA has conducted and provides support for a number of demonstration and pilot projects that examine technologies aimed at improving rail safety and help to demonstrate to railroads the effectiveness of these technologies. According to FRA staff, the agency has put a focus on funding technology demonstration projects and has a cooperative agreement with AAR to do this work. Based on our review of FRA’s list of 143 current R&D projects for fiscal year 2010, 49 of these projects appear to involve demonstrations of new technologies or existing technologies used in new ways to improve safety. For example, there is a current demonstration project examining the use of electronically controlled pneumatic brakes. Past demonstration projects have examined a variety of rail safety technologies, including devices that measure track—known as gage restraint measurement systems⁷⁰—vehicle/track interaction technology and automated inspection devices. Additionally, an FRA risk-reduction grant program supports several ongoing pilot projects with railroads, two of which are examining technologies aimed at continuously testing track to collect data on the track’s performance as well as to

⁶⁹The Transportation Research Board’s Committee for Review of the FRA Research and Development Program includes members from government, the railroad industry, academia, and labor. See Transportation Research Board, *Review of the Federal Railroad Administration Research and Development Program: Letter Report February 2010* (Washington, D.C.: Feb. 24, 2010).

⁷⁰Gage refers to the distance between the two rails of a track, which, if changed, could cause a derailment. Gage restraint is the ability of rail infrastructure to maintain this requisite distance, which can be affected by problems such as defective rail ties or changes in the underlying material the track sits on.

Analysis of Technology Costs and Benefits

identify defects.⁷¹ FRA produces summary reports of some of its R&D efforts and publishes these reports on its Web site.

FRA has taken recent actions to analyze the potential costs and benefits to railroads of implementing new rail safety technologies. When issuing the final rule on electronically controlled pneumatic brakes, FRA conducted a cost-benefit analysis and included this information in the rule. Additionally, FRA analyzed potential return on investments for vehicle/track interaction technology to demonstrate to freight railroads potential cost-savings that could be achieved from implementing this technology by preventing derailments and reducing the need for emergency repairs or slow speed orders on sections of track with defective rail. FRA staff noted that railroads generally will not adopt a new technology unless it can be demonstrated to have a positive return on investment within 1 to 2 years. FRA staff also noted that because the agency demonstrated a positive return on investment for a new vehicle/track interaction system, a major Class I freight railroad adopted the technology.

Issuance and Revision of Regulations

FRA has also issued or revised regulations and is planning further regulatory changes in an attempt to encourage the use of new rail safety technologies. For example:

- FRA issued final regulations promoting the use of electronically controlled pneumatic brakes in October 2008.⁷² The regulations create an incentive for installing this technology by allowing railroads that install these brakes and comply with the regulations to conduct less frequent brake inspections, thereby decreasing the railroads' inspection costs and potentially allowing for more frequent train operations. Prior to the establishment of these regulations, railroads were not permitted to use these specialized braking systems without first applying for an exemption from existing FRA regulations. FRA will provide an exemption from existing regulations on a case-by-case basis to railroads that seek such approval. For example, before PTC was required by law, FRA issued regulatory exemptions and eventually established regulations promoting

⁷¹ According to FRA officials, the agency awarded \$433,000 in grants to seven pilot projects in fiscal year 2009 and an additional \$350,000 to five of those projects in fiscal year 2010. In addition to this funding, FRA officials told us that the railroads cover the majority of the costs associated with these pilots.

⁷² 49 C.F.R. § 232.

the use of PTC.⁷³ FRA has also issued regulatory exemptions allowing for the use of unmanned track inspection machines to monitor track conditions and crash energy management designs in passenger rail vehicles.

- FRA is currently working with the Railroad Safety Advisory Committee to revise its track inspection regulations, which, according to some experts and stakeholders we spoke with, create a disincentive for railroads to implement new track inspection technologies. As previously discussed, current FRA regulations generally require railroads to take remedial action, such as limiting train speeds or replacing track, when a track defect is found.⁷⁴ Stakeholders we spoke with noted that using newer track inspection technologies would detect a greater number of small, relatively minor defects that pose little to no safety risk, along with more significant defects. However, stakeholders stated that FRA's current track inspection regulations could create a situation in which railroads using newer inspection technologies might find more small defects than they could practically examine and fix in a timely manner, and could be held liable for identifying defects they did not quickly repair. To account for these newer technologies, FRA staff said they are considering changes to the remedial actions railroads must take in response to identified rail defects. FRA expects to issue a notice of proposed rulemaking on this and other changes to its track inspection regulations in the spring of 2011. Additionally, pursuant to its safety strategy for high-speed rail, FRA officials said they are considering revisions to FRA's passenger vehicle regulations to encourage the implementation of technologies that monitor the condition of rail vehicles, although the agency has not yet identified these specific requirements.
- The Rail Safety Improvement Act of 2008 also requires FRA to take action in two specific ways to encourage the use of rail safety technologies in addition to PTC. First, the act requires FRA to prescribe standards, regulations, guidance, or orders by October 2009 for railroads to implement rail safety technologies in areas of track without signals or PTC. FRA officials began this effort in September 2010 by proposing that the Railroad Safety Advisory Committee establish a task force to develop a proposed rule. This proposal was accepted; however, the task force will delay meeting until representatives serving on another task force involved

⁷³ 49 C.F.R. §§ 209, 234, and 236.

⁷⁴ 49 C.F.R. § 213.113.

in PTC issues are available.⁷⁵ FRA staff stated that the agency has delayed meeting the October 2009 requirement because FRA gave priority to the PTC rulemaking. Second, by October 2012, FRA must develop regulations requiring Class I freight railroads, Amtrak, commuter railroads, and other railroads that FRA determines have an inadequate safety record to develop a risk-reduction program that includes a technology implementation plan describing railroads' efforts to implement new rail safety technologies.⁷⁶ FRA issued an advanced notice of proposed rulemaking on December 8, 2010, seeking comment on the possible requirements of this program.

The National Academies' Transportation Research Board has identified a number of best practices for encouraging the implementation of new technologies. Of these best practices, those most applicable to FRA's efforts fall into four key areas:⁷⁷

- *Early involvement of users:* Involving potential users of a technology early on in its development, such as seeking information from users about their needs and enlisting their assistance, can help ensure that products developed respond to users' requirements.
- *Demonstrating technology effectiveness:* Agency efforts aimed at demonstrating the effectiveness of a technology can help other potential users decide whether to implement the technology. Activities that can help to demonstrate a technology's effectiveness include supporting demonstrations or pilot projects and conducting cost/benefit or similar analyses.

⁷⁵FRA officials told us that the timing of the task force's first meeting and its membership will be discussed at the December 2010 Railroad Safety Advisory Committee meeting.

⁷⁶49 U.S.C. § 20156(d).

⁷⁷The Transportation Research Board has identified a number of other best practices. See Transportation Research Board, *Transportation Technology Transfer: Successes, Challenges, and Needs: A Synthesis of Highway Practice*, National Cooperative Highway Research Program Synthesis 355 (Washington, D.C.: 2005); and *Managing Technology Transfer: A Strategy for the Federal Highway Administration*, Special Report 256 (Washington, D.C.: 1999). These reports focused on technologies related to highways, but the practices are applicable to other transportation modes, such as railroads. We are citing in this report those best practices we identified as most applicable to FRA's efforts to promote the implementation of new rail safety technologies on the basis of our review of these Transportation Research Board studies.

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- *Offering incentives:* Activities to provide financial assistance and efforts to revise regulations to create other incentives can help encourage the implementation of new technologies.
 - *Monitoring and reporting on technology adoption:* Careful monitoring of the acceptance, adoption, refinement, and satisfaction among users of the technologies being promoted can provide lessons learned about agency efforts to encourage technology implementation. Reporting this information can help demonstrate program results and build support for the agency's efforts.

The actions we previously discussed that FRA has taken to encourage the implementation of rail safety technologies align with most of these practices and help to address some of the implementation challenges experts identified, including uncertainty about technology effectiveness and regulatory disincentives. Specifically, FRA's collaboration with the railroad industry in its R&D efforts involves potential technology users early and helps to ensure its efforts address industry needs while also expediting the potential adoption of new technologies. FRA's sponsorship of demonstration and pilot projects and its analyses of technology costs and benefits help to demonstrate the effectiveness of new technologies. FRA's current efforts to revise some track inspection regulations may address the disincentives in these regulations that discourage railroads from implementing new inspection technologies. Additionally, FRA has a grant program to provide funding for implementing new rail safety technologies, although, at present, the program has been prioritized for PTC and is not being used to fund implementation of other types of rail safety technologies.

Although FRA has taken actions that align to most of the best practices previously identified, the agency lacks a method to effectively monitor implementation of new rail safety technologies that would allow it to better demonstrate the results of its efforts. Specifically, FRA officials stated that the agency does not have a method to track the extent to which the railroad industry implements technologies that FRA's R&D efforts contributed to developing. FRA staff said they have some information about the use of such new technologies, but this information is not comprehensive. For example, FRA officials said they would be aware of a railroad adopting a new safety technology if the railroad is required to seek regulatory exemption from FRA for its use. Our past work looking at the R&D program of DOT's Office of Pipeline Safety—now within the Department's Pipeline and Hazardous Materials Safety Administration—has shown that agencies that monitor and report on industry adoption of

technologies supported by the agency's R&D efforts can better assess the effectiveness of those R&D efforts.⁷⁸ Specifically, the Pipeline and Hazardous Materials Safety Administration monitors and reports on its Web site the number of technologies supported by the agency's R&D efforts that have been commercialized. Without a similar method to monitor and report on the adoption of technologies supported by FRA's R&D efforts, the agency lacks information it could use to refine future R&D efforts or help demonstrate the results of its R&D program, an important consideration because FRA is currently in the process of updating its R&D strategic plan. FRA's last R&D strategic plan included the goal to expedite widespread deployment of new technologies that have the potential for significant improvement in track safety—a goal for which information about the industry's adoption of new technologies could be useful for demonstrating results.⁷⁹

Additionally, 15 of the 20 experts we spoke with indicated that FRA could do more to encourage technology implementation and suggested actions that align with the Transportation Research Board's best practices. Specifically, 3 experts said that FRA should conduct more demonstration or pilot projects, and 4 experts said that FRA should do more to identify the costs and benefits of implementing new technologies—actions that align with the best practice of demonstrating technology effectiveness. Also, 8 experts said that FRA should offer more financial assistance, and 6 experts said that the agency should revise its regulations to provide incentives for the introduction of new technologies—actions that align with the best practice of offering incentives. While additional use of the best practices identified by the Transportation Research Board could better encourage the implementation of rail safety technologies, we are not making a recommendation at this time because FRA has other efforts that it needs to give priority to, such as overseeing investment in high-speed passenger rail and reforming its hours of service regulations.

Conclusions

Although the safety of U.S. rail continues to improve, recent railroad accidents prompted the enactment of the Rail Safety Improvement Act of 2008, including the requirement to implement PTC. Other recently enacted

⁷⁸GAO, *Pipeline Safety: Systematic Process Needed to Evaluate Outcomes of Research and Development Program*, [GAO-03-746](#) (Washington, D.C.: June 30, 2003).

⁷⁹Federal Railroad Administration, *Five-Year Strategic Plan for Railroad Research, Development, and Demonstrations* (Washington, D.C.: March 2002).

laws indicate significant interest in expanding passenger rail services, particularly high-speed passenger services, which will change the nature of the mode and introduce new safety risks. The strategic development and implementation of PTC and other new rail safety technologies can help FRA and the industry address these risks while ensuring that rail remains a safe form of transportation.

The railroad industry is making progress in developing and implementing PTC, but much remains to be accomplished to develop, test, and install fully functional PTC systems in time to meet the 2015 implementation deadline. At present, it is unclear whether various issues—such as the lack of mature PTC components and the cost of implementation, particularly to commuter and smaller freight railroads—could result in railroads missing this deadline or lead to other operational impacts for railroads. However, the PTC implementation deadline is still 5 years away, so it is too soon to determine for certain whether the industry will be able to meet it. This timing presents an opportunity to look ahead at what risks lie in wait that could jeopardize successful implementation and identify potential strategies to address them, rather than wait and see what problems develop and were not addressed. FRA will have the chance to publicly identify such risks, as well as potential ways Congress, the agency, or other stakeholders could address them, when it reports to Congress on PTC implementation progress in 2012. Identifying and mitigating risks sooner, rather than later, would better ensure a reliable PTC system can be fully implemented to provide the intended safety benefits of this technology without resulting in unintended consequences.

While recent laws have expanded FRA's role, its mission to promote safety remains a core responsibility. Much focus has been placed on implementing PTC to address accidents caused by human factors, but technologies besides PTC hold promise for improving safety by addressing other accident causes, such as problems with track or equipment. While FRA has employed several key best practices for encouraging the use of new technologies, employing a method to monitor and report on the industry's adoption of new technologies that FRA was involved in developing could provide useful information for demonstrating the results of its R&D program and refining future efforts. Importantly, such efforts could help the agency better fulfill its mission to promote safety throughout the national rail network.

Recommendations for Executive Action

We recommend that the Secretary of Transportation take the following two actions:

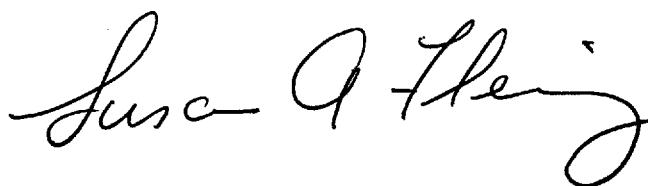
- To support the effective identification and mitigation of risks to the successful fulfillment of PTC requirements by 2015, direct the Administrator of FRA to include in FRA's 2012 report to Congress an analysis of
 - the likelihood that railroads will meet the PTC implementation deadline;
 - the risks to successful implementation of PTC; and
 - actions Congress, railroads, or other stakeholders can take to mitigate risks to successful PTC implementation.
- To better encourage the implementation of rail safety technologies other than PTC, direct the Administrator of FRA to develop and implement a method for monitoring and reporting information on the adoption of technologies supported by FRA's R&D efforts.

Agency Comments

We provided a draft of this report to the Department of Transportation for review and comment. DOT provided technical clarifications, which we incorporated into the report as appropriate. DOT also said that it would consider our recommendations. We also provided a draft of this report to Amtrak for its review and comment. Amtrak provided a technical comment, which we incorporated.

As we agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution of it until 30 days from the date of this letter. At that time, we will send copies of this report to the appropriate congressional committees, the Secretary of Transportation, and other interested parties. In addition, the report will be available at no charge on GAO's Web site at <http://www.gao.gov>.

If you or your staffs have any questions on this report, please contact me at (202) 512-2834 or flemings@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Contact information and key contributors to this report are listed in appendix IV.

A handwritten signature in black ink, reading "Susan A. Fleming". The signature is written in a cursive, flowing style.

Susan Fleming
Director, Physical Infrastructure Issues

Appendix I: Objectives, Scope, and Methodology

This report discusses (1) the progress railroads have made in developing and implementing positive train control (PTC) and the remaining steps to implement PTC systems; (2) the potential benefits of other rail safety technologies under development as well as the challenges to implementing them; and (3) the extent of the Federal Railroad Administration's (FRA) efforts to fulfill the PTC mandate and encourage the implementation of other rail safety technologies.

To obtain information about railroads' progress in developing and implementing PTC and the steps remaining to implement PTC, we interviewed representatives of the four largest Class I freight railroads (BNSF Railway, CSX Corporation, Norfolk Southern, and Union Pacific); Amtrak; five selected commuter railroads (Massachusetts Bay Transportation Authority (Boston, Massachusetts), Metra (Chicago, Illinois), North County Transit District (San Diego, California), Tri-Rail (Miami and Fort Lauderdale, Florida), and Virginia Railway Express (Washington, D.C.)); selected rail supply companies (ENSCO, MeteorComm, and Ansaldo); railroad industry associations (the Association of American Railroads (AAR), the American Short Line and Regional Railroad Association, and the Railway Supply Institute); and FRA.¹ We selected the commuter railroads to represent a range of geographic locations and levels of ridership, while selecting railroads that had relationships with all four of the largest Class I railroads and included a mix of railroads that both owned and leased track. We selected the railroad supply companies on the basis of recommendations from railroad industry associations and railroads and included all of the major suppliers for key components of the freight railroads' PTC systems. We reviewed PTC development and implementation requirements in the Rail Safety Improvement Act of 2008 and FRA regulations. We also reviewed PTC implementation plans that Class I freight railroads and Amtrak submitted to FRA. In addition, we visited and met with officials at the Transportation Technology Center, Inc. (TTCI), near Pueblo, Colorado, where some PTC components are being tested.

To obtain information about the benefits of other rail safety technologies under development, as well as the challenges to implementing them, we compiled a list of rail safety technologies currently under development in

¹Additionally, we received written answers to our questions from another rail supply company, WabTec, and sought information from another supplier, ARINC, which declined to participate in our review.

the United States on the basis of interviews with railroads, railroad associations, FRA, and the Department of Transportation's Volpe National Transportation Systems Center (Volpe Center). We organized these technologies into four categories and refined this list during the course of our work as we obtained additional information from other stakeholders. We sought periodic feedback on the list from FRA, the Volpe Center, AAR, and TTCI. We limited the scope of these technologies to those that would prevent or mitigate train-to-train collisions and derailments and excluded technologies that addressed other risks or that experts indicated were widely deployed and therefore no longer under development.²

We identified, with assistance from the National Academies' Transportation Research Board, a group of 20 rail safety technology experts from railroads, rail suppliers, federal agencies, labor organizations, and universities (see app. II for a list of these experts). We interviewed these experts about their knowledge of the benefits of the rail safety technologies within the scope of this engagement, as well as their views on the challenges to implementing them, and surveyed them with a standardized assessment tool seeking information about the benefits, maturity, and implementation challenges of all the technologies in our scope. We received completed assessments from 19 of the 20 experts (see app. III for complete assessment results). Based on the rail safety technology experts' responses to our questionnaire, we identified some technologies as being more promising than others. In our questionnaire, we asked experts about their views of these technologies' potential to improve safety, the value of funding additional research and development (R&D) and implementation, and the technologies' current stages of product development. For the purposes of this analysis, we defined a technology as being more promising if it has a higher potential to improve safety, is most worth additional R&D and implementation costs, and is in a later stage of development, which presumably would mean it could be implemented sooner than a technology that is in an earlier development stage. By assigning values to the experts' responses, we determined which of the technologies in our scope most satisfied these three criteria—in other words, which technologies the experts viewed as having the most potential to improve safety, being most worth additional costs, and being

²We did not examine technologies specifically designed to address trespassing and highway-rail grade-crossing accidents, since the causes of these accidents are largely outside the control of railroads. Although we contacted leading government and railroad industry experts to identify rail safety technologies under development, the technologies we identified may not be comprehensive of all such technologies under development.

in the later stages of product development.³ We also interviewed government officials, railroad industry representatives, and academics from the European Union, Japan, and Taiwan about rail safety technologies implemented in other countries, seeking insights about potential differences in implementation. We identified these stakeholders on the basis of input from FRA, the Volpe Center, the Transportation Research Board, and suggestions from foreign officials.

To obtain information about the extent of FRA's efforts to fulfill the PTC mandate and encourage the implementation of other rail safety technologies, we reviewed documentation obtained from FRA officials—including information on R&D projects, technology pilots, guidance, strategic planning, and technology implementation grants—and interviewed FRA officials responsible for the agency's rail safety technology R&D, safety regulatory efforts, and efforts to meet the PTC mandate. We also reviewed FRA's requirements in the Rail Safety Improvement Act of 2008 and related FRA regulations to fulfill the PTC mandate and encourage the implementation of other rail safety technologies. Additionally, we interviewed the experts and other railroad industry stakeholders that we have previously named about their views on FRA's efforts to fulfill the PTC mandate and encourage the implementation of other rail safety technologies. We focused our review on FRA efforts related to the implementation of these technologies and did not attempt to comprehensively review FRA's R&D program. We identified best practices for encouraging the implementation of new technologies by reviewing reports from the National Academies' Transportation Research Board and prior GAO reports.

³In our questionnaire, we asked experts their views on technology maturity using five categories of technology development ordered from earlier to later stages: concept exploration, proof of concept and initial design, refinement and pilot testing, production and some deployment, and widespread industry deployment. Because we focused our review on technologies under development, we excluded from our scope any technologies that a consensus of these experts indicated was widely deployed.

Appendix II: List of Rail Safety Technology Experts

Christopher Barkan, University of Illinois at Urbana-Champaign
Anna Barry, Massachusetts Bay Transportation Authority
John Bell, Federal Transit Administration
Joshua Coran, Talgo
Robert Dorer, Volpe National Transportation Systems Center
Carlton Ho, University of Massachusetts Amherst
Rick Inclima, Brotherhood of Maintenance of Way Employees Division
Semih Kalay, Transportation Technology Center, Inc.
Kevin Kesler, FRA
Francesco Lanza di Scalea, University of California, San Diego
George Long, Siemens Industry
Dan Magnus, KLD Labs
Tim Male, CSX Corporation
Alan Polivka, Transportation Technology Center, Inc.
Thomas Pontolillo, Brotherhood of Locomotive Engineers and Trainmen
Eileen Reilly, Alaska Railroad
Mark Stehly, BNSF Railway
James Stem, United Transportation Union
Michael Trosino, Amtrak
Steve Zwart, Alstom

Appendix III: Detailed Results of Experts' Assessment of Rail Safety Technologies

Following is the tool used to assess experts' views about rail safety technologies under development, complete with detailed results. We do not include the responses for open-ended questions.

Introduction

The U.S. Government Accountability Office (GAO) is an independent, non-partisan agency that assists Congress in evaluating federal programs.

We are interested in your expert professional opinions on a number of technologies for potentially improving railroad safety. We have identified the technologies included in this assessment tool through our first round of interviews with you, other experts and stakeholders, and a review of available literature. These technologies are separated into four categories – Remote Control and Switches, Rolling Stock and Condition Monitoring, Occupant Protection, and Track Inspection and Measurement.

- For the purposes of this review, we have limited our scope to reviewing only those technologies that would potentially increase safety by preventing or mitigating train-to-train collisions and derailments.

We ask that you please assess the technologies across several factors, providing comments where appropriate. In addition, we are also interested in your thoughts about possible actions that the U.S. Department of Transportation could take to encourage the implementation of new technologies. Lastly, we are interested in your opinion on the extent to which specific issues may pose a challenge to implementing positive train control by the December 31, 2015 deadline.

Instructions for Completing This Tool

You can answer most of the questions easily by checking boxes or filling in blanks. A few questions request short narrative answers. Please note that these blanks will expand to fit your answer.

Please use your mouse to navigate throughout the document by clicking on the field or check box you wish to fill in. Do not use the "Tab" or "Enter" keys as doing so may cause formatting problems.

- To select or deselect a check box, simply click or double click on the box.

**Appendix III: Detailed Results of Experts'
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Deadline

To assist us, we ask that you complete and return this document by June 15, 2010. Please return the completed survey by e-mail. Simply save this file to your computer desktop or hard drive and attach it to your e-mail.

Contact Information

Thanks in advance for taking the time to share your expertise with GAO. If you have any questions about this tool, please contact us. You may direct questions to Andrew Huddleston, Senior Analyst.

Thank you for your help.

Part 1: Remote Control and Switch Technologies

In this section we refer to Remote Control and Switch Technologies.¹ Please use the following descriptions as a guide when thinking about these specific technologies.

Descriptions of technologies referred to in this section	
a. Remote-control locomotives ²	Use of remote control to move trains in yard switching operations or through work zones
b. Remote-control switches	Modifications for enhanced control of track switches from the locomotive or other remote location
c. Switch position monitors/indicators	Devices to monitor and report position of track switches

1. How would you rate your overall level of knowledge of increasing railroad safety through the development and use of the following remote control and switch technologies?

- | | |
|--------------|---------------------------------|
| 1 None | → SKIP TO PART 2 (QUESTION #10) |
| 6 Minimal | → SKIP TO PART 2 (QUESTION #10) |
| 5 Basic | → CONTINUE TO QUESTION #2 |
| 4 Proficient | → CONTINUE TO QUESTION #2 |
| 3 Advanced | → CONTINUE TO QUESTION #2 |

¹The names of the technology categories for parts 1 through 4 of the assessment tool appear differently in this appendix than in the body of this report, since we clarified the names of the technology categories while developing the report to characterize them more accurately.

²Although we included remote-control locomotives in our questionnaire, we excluded this technology from our analysis of the most promising technologies because we focused our analysis on technologies that are currently under development, and, when asked about this technology’s stage in product development, all experts that answered this question indicated they viewed the technology as widely deployed.

2. How much potential, if any, does further development and implementation of the following remote control and switch technologies have for improving rail safety?

Remote control and switch technology	No potential	Low potential	Medium potential	High potential	No basis to judge
a. Remote-control locomotives	4	2	2	3	1
b. Remote-control switches	0	4	4	2	2
c. Switch position monitors/indicators	0	2	3	7	0

3. Considering the potential for additional safety benefits and likely research and development (R&D) costs—regardless of funding source—do you believe *further R&D* of the following remote control and switch technologies would be worth the investment?

Remote control and switch technology	No	Maybe	Yes	No basis to judge
a. Remote-control locomotives	6	3	3	0
b. Remote-control switches	2	3	6	1
c. Switch position monitors/indicators	1	2	9	0

4. Considering the potential for additional safety benefits and likely implementation costs—regardless of funding source—do you believe the *procurement, operation, and maintenance* of the following remote control and switch technologies would be worth the investment?

Remote control and switch technology	No	Maybe	Yes	No basis to judge
a. Remote-control locomotives	5	4	3	0
b. Remote-control switches	1	4	6	1
c. Switch position monitors/indicators	1	4	7	0

**Appendix III: Detailed Results of Experts'
Assessment of Rail Safety Technologies**

5. At what product development stage are the following remote control and switch technologies in the United States?

Remote control and switch technology	Concept exploration	Proof of concept and initial design	Refinement and pilot testing	Production and some deployment	Widespread industry deployment	No basis to judge
a. Remote-control locomotives	0	0	0	0	10	2
b. Remote-control switches	0	0	0	4	5	3
c. Switch position monitors/indicators	0	0	2	6	2	2

6. How much of a challenge, if any, do the following issues present for the implementation of remote-control locomotives?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	1	7	1	0	3
b. Lack of incentive under current regulations	6	2	0	1	3
c. Technology cannot be used without a regulatory waiver	5	0	1	3	3
d. Lack of interoperability with existing systems and equipment	5	2	1	0	4
e. Uncertainty about the effectiveness of the technology	3	2	3	0	4

**Appendix III: Detailed Results of Experts'
Assessment of Rail Safety Technologies**

7. How much of a challenge, if any, do the following issues present for the implementation of remote-control switches?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	4	6	0	2
b. Lack of incentive under current regulations	7	2	1	1	1
c. Technology cannot be used without a regulatory waiver	8	1	1	0	2
d. Lack of interoperability with existing systems and equipment	4	5	0	1	2
e. Uncertainty about the effectiveness of the technology	6	2	1	1	2

8. How much of a challenge, if any, do the following issues present for the implementation of switch position monitors/indicators?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	1	3	7	0	1
b. Lack of incentive under current regulations	6	3	2	0	1
c. Technology cannot be used without a regulatory waiver	8	0	1	1	2
d. Lack of interoperability with existing systems and equipment	6	3	1	0	2
e. Uncertainty about the effectiveness of the technology	6	5	1	0	0

9. What other challenges, if any, that are not listed above impede the implementation of remote control and switch technologies in the United States?

Part 2: Rolling Stock and Condition Monitoring Technologies

In this section we refer to Rolling Stock and Condition Monitoring Technologies. Please use the following descriptions as a guide when thinking about these specific technologies.

Descriptions of technologies referred to in this section	
a. Electronically controlled pneumatic brakes	Advanced braking system that increases the speed at which brake signals are sent through a train, which can reduce stopping distances and prevent braking-related derailments
b. Improved design of tank cars and other hazardous material cars	Improvements to hazardous material-carrying cars (e.g. structural integrity, damage tolerance) that reduce potential release of hazardous material in the event of an accident
c. High performance wheel steels	Development of alternative wheel steels to extend wheel life and improve safety
d. On-board condition monitoring systems	Systems installed on rail cars that continuously monitor mechanical components including bearing temperature, bearing and wheel defects, and longitudinal impacts
e. Wayside detectors	Condition monitoring systems installed along tracks that can identify defects in various rolling stock components as trains drive by. For example, acoustic bearing detectors, wheel impact load detectors, truck performance detectors, cracked wheel detectors, wheel profile measurement.

10. How would you rate your overall level of knowledge of increasing railroad safety through the development and use of the following rolling stock and condition monitoring technologies?

- | | |
|--------------|---------------------------------|
| 1 None | → SKIP TO PART 3 (QUESTION #21) |
| 4 Minimal | → SKIP TO PART 3 (QUESTION #21) |
| 5 Basic | → CONTINUE TO QUESTION #11 |
| 5 Proficient | → CONTINUE TO QUESTION #11 |
| 4 Advanced | → CONTINUE TO QUESTION #11 |

11. How much potential, if any, does further development and implementation of the following rolling stock and condition monitoring technologies have for improving rail safety?

Rolling stock and condition monitoring technology	No potential	Low potential	Medium potential	High potential	No basis to judge
a. Electronically controlled pneumatic brakes	0	0	5	7	2
b. Improved design of tank cars and other hazardous material cars	0	1	5	7	1
c. High performance wheel steels	0	1	8	4	1
d. On-board condition monitoring systems	0	3	4	7	0
e. Wayside detectors	0	2	2	10	0

12. Considering the potential for additional safety benefits and likely research and development (R&D) costs—regardless of funding source—do you believe *further R&D* of the following rolling stock and condition monitoring technologies would be worth the investment?

Rolling stock and condition monitoring technology	No	Maybe	Yes	No basis to judge
a. Electronically controlled pneumatic brakes	1	1	11	1
b. Improved design of tank cars and other hazardous material cars	0	2	11	1
c. High performance wheel steels	0	3	10	1
d. On-board condition monitoring systems	1	3	10	0
e. Wayside detectors	1	0	13	0

Appendix III: Detailed Results of Experts'
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13. Considering the potential for additional safety benefits and likely implementation costs—regardless of funding source—do you believe the *procurement, operation, and maintenance* of the following rolling stock and condition monitoring technologies would be worth the investment?

Rolling stock and condition monitoring technology	No	Maybe	Yes	No basis to judge
a. Electronically controlled pneumatic brakes	0	3	10	1
b. Improved design of tank cars and other hazardous material cars	0	3	10	1
c. High performance wheel steels	0	4	9	1
d. On-board condition monitoring systems	2	5	7	0
e. Wayside detectors	0	2	12	0

14. At what product development stage are the following rolling stock and condition monitoring technologies in the United States?

Rolling stock and condition monitoring technology	Concept exploration	Proof of concept and initial design	Refinement and pilot testing	Production and some deployment	Widespread industry deployment	No basis to judge
a. Electronically controlled pneumatic brakes	0	0	4	7	1	2
b. Improved design of tank cars and other hazardous material cars	0	4	2	4	1	3
c. High performance wheel steels	0	1	2	2	0	9
d. On-board condition monitoring systems	1	4	2	5	1	1
e. Wayside detectors	0	0	0	4	10	0

Appendix III: Detailed Results of Experts'
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15. How much of a challenge, if any, do the following issues present for the implementation of electronically controlled pneumatic brakes?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	2	10	0	2
b. Lack of incentive under current regulations	3	5	2	0	4
c. Technology cannot be used without a regulatory waiver	5	3	2	1	3
d. Lack of interoperability with existing systems and equipment	0	1	11	0	2
e. Uncertainty about the effectiveness of the technology	5	3	3	0	3

16. How much of a challenge, if any, do the following issues present for the implementation of improved design of tank cars and other hazardous material cars?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	1	10	0	3
b. Lack of incentive under current regulations	7	2	2	0	3
c. Technology cannot be used without a regulatory waiver	7	3	1	1	2
d. Lack of interoperability with existing systems and equipment	7	4	0	1	2
e. Uncertainty about the effectiveness of the technology	4	4	4	0	2

17. How much of a challenge, if any, do the following issues present for the implementation of high performance wheel steels?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	3	6	0	5
b. Lack of incentive under current regulations	7	2	0	1	4
c. Technology cannot be used without a regulatory waiver	6	2	0	2	4
d. Lack of interoperability with existing systems and equipment	5	3	0	2	4
e. Uncertainty about the effectiveness of the technology	3	7	0	0	4

18. How much of a challenge, if any, do the following issues present for the implementation of on-board condition monitoring systems?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	2	11	0	1
b. Lack of incentive under current regulations	6	3	5	0	0
c. Technology cannot be used without a regulatory waiver	9	1	0	4	0
d. Lack of interoperability with existing systems and equipment	4	6	2	0	2
e. Uncertainty about the effectiveness of the technology	3	6	5	0	0

19. How much of a challenge, if any, do the following issues present for the implementation of wayside detectors?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	1	7	5	0	1
b. Lack of incentive under current regulations	7	2	5	0	0
c. Technology cannot be used without a regulatory waiver	8	2	1	3	0
d. Lack of interoperability with existing systems and equipment	7	6	0	1	0
e. Uncertainty about the effectiveness of the technology	9	4	0	1	0

20. What other challenges, if any, that are not listed above impede the implementation of rolling stock and condition monitoring technologies in the United States?

Part 3: Occupant Protection Technologies

In this section we refer to Occupant Protection Technologies. Please use the following descriptions as a guide when thinking about these specific technologies.

Descriptions of technologies referred to in this section	
a. Crash energy management	Rail car designs with crumple zones that absorb energy from a collision in order to maintain occupant volume and reduce secondary impact velocities
b. Improved design of interior passenger car fixtures	Design improvements to passenger car fixtures, such as tables and seats, to reduce the severity of injury during an accident

21. How would you rate your overall level of knowledge of increasing railroad safety through the development and use of the following occupant protection technologies?

- 3 None →SKIP TO PART 4 (QUESTION #29)
- 7 Minimal →SKIP TO PART 4 (QUESTION #29)
- 1 Basic →CONTINUE TO QUESTION #22
- 4 Proficient →CONTINUE TO QUESTION #22
- 4 Advanced →CONTINUE TO QUESTION #22

22. How much potential, if any, does further development and implementation of the following occupant protection technologies have for improving rail safety?

Occupant protection technology	No potential	Low potential	Medium potential	High potential	No basis to judge
a. Crash energy management	0	0	2	7	2
b. Improved design of interior passenger car fixtures	0	0	3	6	2

23. Considering the potential for additional safety benefits and likely research and development (R&D) costs—regardless of funding source—do you believe *further R&D* of the following occupant protection technologies would be worth the investment?

Occupant protection technology	No	Maybe	Yes	No basis to judge
a. Crash energy management	0	0	9	2
b. Improved design of interior passenger car fixtures	0	1	8	2

Appendix III: Detailed Results of Experts'
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24. Considering the potential for additional safety benefits and likely implementation costs—regardless of funding source—do you believe the *procurement, operation, and maintenance* of the following occupant protection technologies would be worth the investment?

Occupant protection technology	No	Maybe	Yes	No basis to judge
a. Crash energy management	1	2	6	2
b. Improved design of interior passenger car fixtures	1	1	7	2

25. At what product development stage are the following occupant protection technologies in the United States?

Occupant protection technology	Concept exploration	Proof of concept and initial design	Refinement and pilot testing	Production and some deployment	Widespread industry deployment	No basis to judge
a. Crash energy management	0	1	2	6	0	2
b. Improved design of interior passenger car fixtures	1	0	3	4	1	2

26. How much of a challenge, if any, do the following issues present for the implementation of crash energy management?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	2	7	0	2
b. Lack of incentive under current regulations	4	3	2	0	2
c. Technology cannot be used without a regulatory waiver	5	1	3	0	2
d. Lack of interoperability with existing systems and equipment	3	3	3	0	2
e. Uncertainty about the effectiveness of the technology	3	5	1	0	2

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27. How much of a challenge, if any, do the following issues present for the implementation of improved design of interior passenger car fixtures?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	7	2	0	2
b. Lack of incentive under current regulations	4	2	3	0	2
c. Technology cannot be used without a regulatory waiver	8	0	1	0	2
d. Lack of interoperability with existing systems and equipment	7	2	0	0	2
e. Uncertainty about the effectiveness of the technology	4	3	2	0	2

28. What other challenges, if any, that are not listed above impede the implementation of occupant protection technologies in the United States?

Part 4: Track Inspection and Measurement Technologies

In this section we refer to Track Inspection and Measurement Technologies. Please use the following descriptions as a guide when thinking about these specific technologies.

Descriptions of technologies referred to in this section	
a. Machine vision-based automated track inspection	Automated visual inspection of track defects (e.g. fractures at joint bars and at switch points) through the use of digital imaging or video
b. Laser-based non-contact ultrasonic rail inspection	Enhancement to existing ultrasonic rail inspection techniques using lasers to improve detection of rail defects, both internal and surface
c. Ultrasonic phased array rail defect imaging	Use of phased arrays to more accurately determine the size and shape of a rail flaw
d. Rail longitudinal stress detection systems	Systems for detecting internal rail stresses that could lead to track buckling or fractures
e. Portable ride quality meters	Portable devices used on board of rail cars to measure ride quality and identify possible poor track conditions or poor wheel-rail interactions
f. Autonomous track measurement systems	Devices installed on revenue service trains that measure track qualities (e.g. track geometry, gage restraint, and rail cant) in real time
g. Track modulus measurement systems	Systems used to detect weak spots in track ballast that can weaken the vertical forces of rail and lead to instability or derailments
h. Intrusion detection systems	Systems that provide engineers and dispatchers timely information on the status of track sections and crossings, including any unauthorized intrusions, to allow them sufficient time to decrease speed or stop
i. Bridge integrity monitoring systems	Sensor-based systems used to detect bridge damage or structural defects that could lead to collapse

29. How would you rate your overall level of knowledge of increasing railroad safety through the development and use of the following track inspection and measurement technologies?

- | | |
|--------------|---------------------------------|
| 1 None | → SKIP TO PART 5 (QUESTION #44) |
| 4 Minimal | → SKIP TO PART 5 (QUESTION #44) |
| 2 Basic | → CONTINUE TO QUESTION #30 |
| 5 Proficient | → CONTINUE TO QUESTION #30 |
| 7 Advanced | → CONTINUE TO QUESTION #30 |

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30. How much potential, if any, does further development and implementation of the following track inspection and measurement technologies have for improving rail safety?

Track inspection and measurement technology	No potential	Low potential	Medium potential	High potential	No basis to judge
a. Machine vision-based automated track inspection	0	2	3	8	1
b. Laser-based non-contact ultrasonic rail inspection	0	0	7	6	1
c. Ultrasonic phased array rail defect imaging	0	0	8	2	4
d. Rail longitudinal stress detection systems	0	3	2	9	0
e. Portable ride quality meters	1	2	7	2	2
f. Autonomous track measurement systems	0	3	4	6	0
g. Track modulus measurement systems	1	3	6	2	2
h. Intrusion detection systems	0	2	7	4	1
i. Bridge integrity monitoring systems	0	0	6	7	1

31. Considering the potential for additional safety benefits and likely research and development (R&D) costs—regardless of funding source—do you believe *further R&D* of the following track inspection and measurement technologies would be worth the investment?

Track inspection and measurement technology	No	Maybe	Yes	No basis to judge
a. Machine vision-based automated track inspection	1	1	10	2
b. Laser-based non-contact ultrasonic rail inspection	0	2	10	2
c. Ultrasonic phased array rail defect imaging	0	1	10	3
d. Rail longitudinal stress detection systems	0	4	8	2
e. Portable ride quality meters	1	9	2	2
f. Autonomous track measurement systems	3	2	8	1
g. Track modulus measurement systems	3	3	6	2
h. Intrusion detection systems	1	4	8	1
i. Bridge integrity monitoring systems	0	3	11	0

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32. Considering the potential for additional safety benefits and likely implementation costs—regardless of funding source—do you believe the *procurement, operation, and maintenance* of the following track inspection and measurement technologies would be worth the investment?

Track inspection and measurement technology	No	Maybe	Yes	No basis to judge
a. Machine vision-based automated track inspection	3	2	9	0
b. Laser-based non-contact ultrasonic rail inspection	0	6	7	1
c. Ultrasonic phased array rail defect imaging	0	5	7	2
d. Rail longitudinal stress detection systems	1	2	9	2
e. Portable ride quality meters	1	7	4	2
f. Autonomous track measurement systems	2	3	8	1
g. Track modulus measurement systems	3	4	5	2
h. Intrusion detection systems	0	6	7	1
i. Bridge integrity monitoring systems	0	3	11	0

33. At what product development stage are the following track inspection and measurement technologies in the United States?

Track inspection and measurement technology	Concept exploration	Proof of concept and initial design	Refinement and pilot testing	Production and some deployment	Widespread industry deployment	No basis to judge
a. Machine vision-based automated track inspection	0	2	5	5	0	2
b. Laser-based non-contact ultrasonic rail inspection	0	3	5	3	0	3
c. Ultrasonic phased array rail defect imaging	0	5	4	2	0	3
d. Rail longitudinal stress detection systems	2	3	1	6	0	2
e. Portable ride quality meters	0	0	1	6	4	3
f. Autonomous track measurement systems	1	1	3	6	1	2
g. Track modulus measurement systems	1	1	4	5	0	3
h. Intrusion detection systems	1	0	3	4	2	3
i. Bridge integrity monitoring systems	1	2	3	7	0	1

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34. How much of a challenge, if any, do the following issues present for the implementation of machine vision-based automated track inspection?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	6	7	0	1
b. Lack of incentive under current regulations	2	4	7	0	1
c. Technology cannot be used without a regulatory waiver	3	1	3	3	0
d. Lack of interoperability with existing systems and equipment	7	2	1	2	2
e. Uncertainty about the effectiveness of the technology	1	7	5	0	1

35. How much of a challenge, if any, do the following issues present for the implementation of laser-based non-contact ultrasonic rail inspection?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	5	3	0	5
b. Lack of incentive under current regulations	4	6	3	0	1
c. Technology cannot be used without a regulatory waiver	6	2	2	2	2
d. Lack of interoperability with existing systems and equipment	8	2	0	1	3
e. Uncertainty about the effectiveness of the technology	2	2	9	0	1

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36. How much of a challenge, if any, do the following issues present for the implementation of ultrasonic phased array rail defect imaging?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	8	2	0	4
b. Lack of incentive under current regulations	4	6	1	1	2
c. Technology cannot be used without a regulatory waiver	5	4	0	1	4
d. Lack of interoperability with existing systems and equipment	8	2	0	1	3
e. Uncertainty about the effectiveness of the technology	1	3	8	0	2

37. How much of a challenge, if any, do the following issues present for the implementation of rail longitudinal stress detection systems?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	3	6	0	5
b. Lack of incentive under current regulations	5	3	3	1	2
c. Technology cannot be used without a regulatory waiver	6	2	0	3	3
d. Lack of interoperability with existing systems and equipment	6	3	0	2	3
e. Uncertainty about the effectiveness of the technology	1	4	7	0	2

**Appendix III: Detailed Results of Experts'
Assessment of Rail Safety Technologies**

38. How much of a challenge, if any, do the following issues present for the implementation of portable ride quality meters?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	2	7	0	0	5
b. Lack of incentive under current regulations	4	5	2	0	3
c. Technology cannot be used without a regulatory waiver	7	3	0	1	3
d. Lack of interoperability with existing systems and equipment	8	2	0	1	3
e. Uncertainty about the effectiveness of the technology	5	6	0	0	3

39. How much of a challenge, if any, do the following issues present for the implementation of autonomous track measurement systems?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	6	6	0	2
b. Lack of incentive under current regulations	2	5	5	1	1
c. Technology cannot be used without a regulatory waiver	4	2	3	3	2
d. Lack of interoperability with existing systems and equipment	5	4	1	2	2
e. Uncertainty about the effectiveness of the technology	2	6	4	0	2

**Appendix III: Detailed Results of Experts'
Assessment of Rail Safety Technologies**

40. How much of a challenge, if any, do the following issues present for the implementation of track modulus measurement systems?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	5	5	0	4
b. Lack of incentive under current regulations	4	7	1	1	1
c. Technology cannot be used without a regulatory waiver	8	2	0	3	1
d. Lack of interoperability with existing systems and equipment	8	3	0	2	1
e. Uncertainty about the effectiveness of the technology	1	4	8	0	1

41. How much of a challenge, if any, do the following issues present for the implementation of intrusion detection systems?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	4	5	0	5
b. Lack of incentive under current regulations	6	3	3	0	2
c. Technology cannot be used without a regulatory waiver	10	0	0	1	3
d. Lack of interoperability with existing systems and equipment	5	6	0	0	3
e. Uncertainty about the effectiveness of the technology	1	9	2	0	2

**Appendix III: Detailed Results of Experts'
Assessment of Rail Safety Technologies**

42. How much of a challenge, if any, do the following issues present for the implementation of bridge integrity monitoring systems?

Challenge	Not a challenge	Minor challenge	Major challenge	Does not apply	No basis to judge
a. Costs	0	7	5	0	2
b. Lack of incentive under current regulations	7	5	1	0	1
c. Technology cannot be used without a regulatory waiver	9	1	0	2	2
d. Lack of interoperability with existing systems and equipment	5	6	0	2	1
e. Uncertainty about the effectiveness of the technology	2	7	4	0	1

43. What other challenges, if any, that are not listed above impede the implementation of track inspection and measurement technologies in the United States?

Part 5: Government Actions

44. What further actions, if any, could the U.S. Department of Transportation take to encourage the implementation of new rail safety technologies?

Part 6: Positive Train Control

45. How would you rate your overall level of knowledge about the development and implementation of positive train control in the United States?

- | | |
|--------------|----------------------------|
| 1 None | → SKIP TO QUESTION #49 |
| 2 Minimal | → SKIP TO QUESTION #49 |
| 8 Basic | → CONTINUE TO QUESTION #46 |
| 2 Proficient | → CONTINUE TO QUESTION #46 |
| 6 Advanced | → CONTINUE TO QUESTION #46 |

46. How much of a challenge, if any, do the following issues present to meeting the December 31, 2015 deadline for implementing positive train control (PTC)?

Issue	Not a challenge	Minor challenge	Major challenge	No basis to judge
a. Achieving interoperability among all railroads	0	2	14	0
b. Refining braking algorithms	0	9	7	0
c. Acquisition of adequate spectrum in the 220 MHz frequency, specifically in dense, metropolitan areas	0	5	8	3
d. Development of new high performance radio equipment	1	4	8	3
e. Technological maturity of other PTC components	1	3	11	1
f. Ability of suppliers to meet demand for PTC products	3	1	10	2
g. Cost to larger railroads (Amtrak and Class I freights)	0	1	15	0
h. Cost to smaller railroads (short lines, regionals, commuters)	0	2	13	1
i. FRA's ability to certify PTC systems in a timely fashion	1	3	10	2

47. What other issues, if any, that are not listed above may present a challenge to meeting the December 31, 2015 deadline for implementing positive train control?

48. What further actions, if any, could the U.S. Department of Transportation take to facilitate the implementation of positive train control in order to meet the December 31, 2015 deadline?

**Part 7: Additional
Comments**

49. What other comments, if any, do you have about the topics covered in this assessment tool?

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

Susan Fleming, (202) 512-2834 or flemings@gao.gov

Staff Acknowledgments

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